JOURNAL OF AGRICULTURAL RESEARCH

VOL. 38 WASHINGTON, D. C., MARCH 1, 1929 No. 5

EFFECT OF MOSAIC DISEASE ON YIELD AND QUALITY OF TOBACCO[1]

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INTRODUCTION

Much has been written about the mosaic disease of tobacco, which is possibly the commonest and most widespread disease affecting this crop. That it is a cause of loss to the tobacco grower is generally accepted, but just how much loss results under given conditions has not been reported except in a single instance.[3] Some growers maintain that the mosaic disease causes no depression in yield or quality. However, observation readily shows that it may markedly retard growth when plants become infected early in the season.

From observations made over the southern Maryland tobacco district for several years past it appears that this disease is more prevalent there than in most other tobacco sections. This fact has been demonstrated by observations made during this time in portions of the tobacco districts of Kentucky, Tennessee, North Carolina, Georgia, and Connecticut. The greater prevalence in southern Maryland may possibly be explained, at least in part, by the facts that there the previous year's crop is usually on the farm while the new crop is under way and that the stripping, grading, and packing of the previous year's crop are conducted simultaneously with the weeding of the seed beds and the transplanting, replanting, and cultivation of the new crop. It is the common practice of workers to go from one of these operations to the other without taking any sanitary precautions. The practice of scattering stalks from the previous year's crop on land that is to be used for growing tobacco during the succeeding year may also account for the prevalence of the disease in some cases. It would seem, therefore, entirely possible for the grower to carry some mosaic infection over from year to year by these practices.

In order to determine the effect of the mosaic disease of tobacco on yield and quality over a period of years experiments were started in 1925 and continued through 1927 at the cooperative tobacco experiment station at Upper Marlboro, Md.

CONDITIONS AND METHODS

Weather conditions have an important effect on the final yield and quality of the tobacco crop for any given year. The ideal growing season is one during which the rainfall is so evenly distributed that

[1] Received for publication Oct. 29, 1928; issued April, 1929. Cooperative investigations between the Agricultural Experiment Station of the University of Maryland and the Office of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Department of Agriculture.

[2] The author acknowledges the cooperation of D. E. Brown and W. M. Lunn in carrying out the work reported.

[3] VALLEAU, W. D., and JOHNSON, E. M. THE EFFECT OF A STRAIN OF TOBACCO MOSAIC ON THE YIELD AND QUALITY OF BURLEY TOBACCO. Phytopathology 17: 523-527. 1927.

the plant makes a rapid and uninterrupted growth from the time of transplanting until maturity. As shown in Table 1, the rainfall at Upper Marlboro was fairly well distributed during each of the three years covered by the test. Although the first part of the 1925 season was so dry that it was necessary to water the plants in transplanting, there was a fairly uniform distribution of rainfall during the remainder of the season. The 1926 season had the best distribution of rainfall, and this was reflected in the crop of that year, which was of better quality than any other crop produced during the test. The rainfall for the 1927 season was deficient during the early part of the growing period but ample during the latter part.

TABLE 1.—*Rainfall at Upper Marlboro, Md., for 10-day periods during June, July, and August, 1925–1927*

Period	1925	1926	1927
	Inches	*Inches*	*Inches*
June 1–10	0	1.04	0
June 11–20	0.04	.52	2.30
June 21–30	1.73	.89	0
Total	1.77	2.45	2.30
July 1–10	2.83	1.56	.48
July 11–20	.32	2.56	.60
July 21–31	3.55	.65	.0
Total	6.70	4.77	1.08
Aug. 1–10	1.12	.54	0
Aug. 11–20	.85	3.70	2.43
Aug. 21–31	.65	2.37	3.06
Total	2.62	6.61	5.49

Every year 10 rows of 50 plants each were planted to the Maryland Broadleaf variety of tobacco. Each row was fertilized each year, previous to transplanting, using the same quantity by weight of a fertilizer mixture applied in quantities equivalent to 800 pounds per acre, and containing by analysis 6 per cent ammonia (NH_3), one-third from dried blood and two-thirds from nitrate of soda; 8 per cent phosphoric acid (P_2O_5), and 10 per cent potash (K_2O). The test was conducted on the same area during the entire period. The soil has been classified as Collington fine sandy loam, heavy subsoil phase.

The tobacco was transplanted across the rows by hand in order to even up possible inequalities in plants. The rows were 3 feet apart, and the plants were spaced 2 feet 10 inches apart in the rows. This is about the usual spacing for tobacco in the southern Maryland district and permits the planting of approximately 5,000 plants on an acre. Thus, in the test each row is equivalent to one-hundredth of an acre. In compiling the data (Table 2) the yields and values for these areas were converted to the acre basis.

Whatever the source of the original infection in the plant bed or field, the grower is undoubtedly very active, unconsciously, in disseminating the disease in cultural practices, such as transplanting, hoeing, and topping. In the process of transplanting, each plant is handled at least two or three times. In hoeing or weeding, the plants may be injured by handling or they may be bruised with the hoe. At topping time each plant is handled and bruised with hands

that have become covered with juice, making the contamination of a considerable part of the crop certain, provided there is any mosaic disease in the growing crop to become a source of infection. In the process of removing the suckers there is further chance of disseminating the disease. However, as appears from the data, inoculations after topping time may not cause serious injury to yield and quality.

The inoculations in this test were made at times that correspond to periods when the plants are handled most by the grower, that is, during transplanting, hoeing, and topping. The inoculations at transplanting time were made from fresh juice of plants showing typical tobacco mosaic, which had been brought in from the field in the previous fall and carried through the winter in the greenhouse. Subsequent inoculations were made during the season from fresh juice of plants that had been inoculated previously. The inoculations were made by pressing juice from leaves showing symptoms of mosaic (fig. 1), and rubbing it on the leaves of plants to be inoculated. The rubbing was not severe enough to bruise the leaves materially. As a rule, distinct symptoms became evident about two weeks after the inoculations were made.

TABLE 2.—*Acre yields, gross values, and average prices of leaf tobacco, uninoculated and inoculated at different periods of growth with mosaic virus, at Upper Marlboro, Md., 1925–1927*

Row No.	Time of inoculation	Acre yield (pounds)				Acre value				Average price per 100 pounds
		1925	1926	1927	Average	1925	1926	1927	Average	
1	Transplanting time	875	869	1,100	948	$76.01	$139.88	$86.56	$100.82	$10.64
2	1 month after transplanting.[a]	975	844	1,216	1,012	55.44	132.75	117.75	101.98	10.08
3	2 months after transplanting.[b]	1,325	1,025	1,444	1,265	176.06	242.53	171.04	196.54	15.54
4	Uninoculated	1,500	1,075	1,394	1,323	260.63	293.50	171.31	241.81	18.28
5	do	1,150	1,356	1,741	1,416	170.13	310.14	202.52	227.60	16.07
6	Transplanting time	706	900	1,263	956	62.64	154.03	102.24	106.30	11.12
7	1 month after transplanting.[a]	975	950	1,450	1,125	56.63	158.19	143.34	119.39	10.61
8	2 months after transplanting.[b]	1,544	1,181	1,525	1,417	205.63	278.58	187.39	223.87	15.80
9	Uninoculated	1,425	1,200	1,597	1,407	236.55	301.06	231.67	256.43	18.23
10	do	1,475	1,488	1,650	1,538	226.81	315.58	197.02	246.47	16.03
	AVERAGE OF DUPLICATE INOCULATIONS									
1 and 6	Transplanting time	791	884	1,181	952	$69.32	$146.95	$94.40	$103.56	$10.88
2 and 7	1 month after transplanting.[a]	975	897	1,333	1,068	55.03	145.47	130.54	110.68	10.36
3 and 8	2 months after transplanting.[b]	1,435	1,103	1,485	1,341	190.84	260.55	179.21	210.20	15.67
4 and 9	Uninoculated	1,462	1,137	1,495	1,365	248.59	297.28	201.49	249.12	18.25
5 and 10	do	1,312	1,422	1,695	1,476	198.47	312.86	199.77	237.03	16.06

[a] About hoeing time. [b] Topping time.

In general, the cultural and other practices of handling the crop were about the same as those used by the growers of this type of tobacco. However, some precautions were taken in order to avoid carrying the disease to the control rows. When it was necessary to hoe, cultivate, or top, the control rows were handled first. At the outset it was feared that the plants in the control rows would not

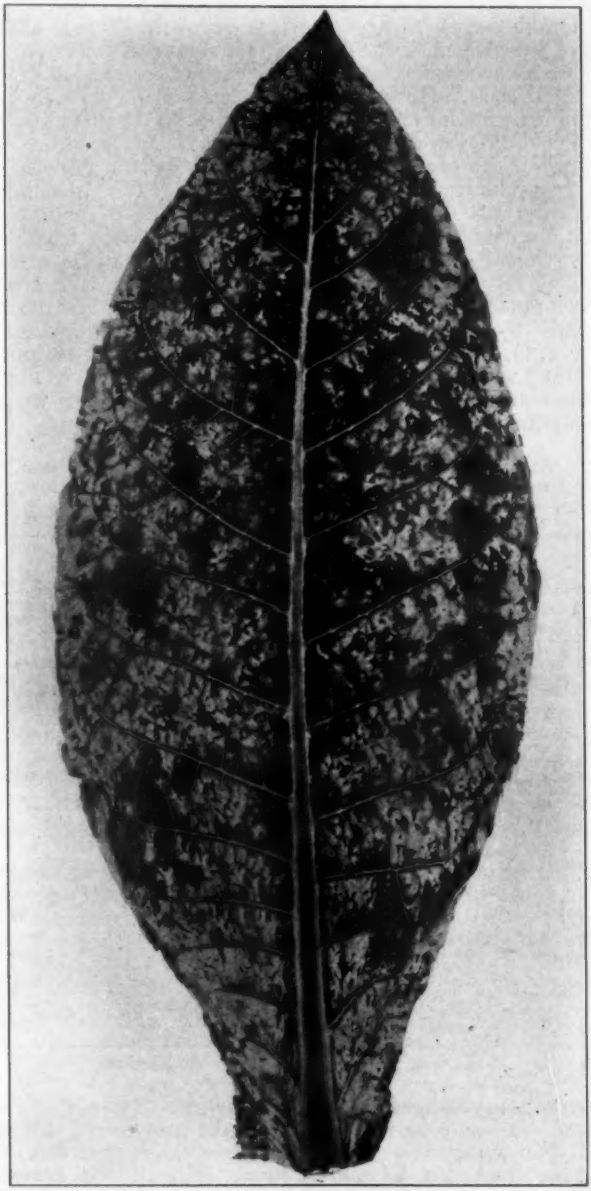

FIGURE 1.—Leaf of tobacco, showing typical symptoms of mosaic disease. Note the light-green and dark-green areas

remain healthy, as they were adjacent to those in diseased rows. Actually, however, there was very little spread of the disease to them. In order to have adequate controls there were two control rows in each group of five rows. (Table 2.) At harvest time the few diseased plants in the control rows were discarded. The rows were arranged in the order shown in Table 2 except in 1927, when the order was reversed in rows 6 to 10, thus causing rows 9 and 10 to be located where rows 7 and 6 had been for the two preceding years. This change was made in order to check the uniformity of the soil and to determine whether the disease would persist in the soil from one year to the next. As can be seen from Table 2, the change in location did not make the results differ materially from those of previous years, thus demonstrating that under the conditions of the test this soil did not carry the disease from year to year and also that it is fairly uniform.

FIGURE 2.—Rows of tobacco plants, showing effect of inoculation with mosaic disease on different dates in 1926: A, Inoculated at transplanting time; B, one month later or about hoeing time; C, two months after transplanting, or at topping time; D and E, uninoculated controls. (See Table 2 for yields)

In the three years covered by the test the tobacco was transplanted about June 1 and harvested about September 1.

RESULTS

The results of the test are summarized in Table 2, which shows the yield and gross value of each individual row calculated to an acre basis for each of the three years covered by the test, with averages for the whole period.

The values reported in Table 2 were obtained in the following manner: When the tobacco was stripped a sample was taken from each grade. These samples were priced by two local buyers who did not know the treatments and judged them wholly on their merits. The prices given by the two buyers were averaged, and a final average for the duplicate samples was made. From this final average the values reported in the table were calculated.

The plants inoculated with mosaic disease early in the season are markedly dwarfed. (Fig. 2.) However, this is not the only damage caused by this disease. The first and most apparent symptom,

and the one from which the disease takes its name, is mottling, or the formation of peculiar green patterns on the leaves. (Fig. 1.) A leaf showing this symptom is usually dwarfed and somewhat discolored after curing. The discoloration in the cured leaf is not so marked as that in the green leaf, nor is it of the same pattern. Associated with this mottling there may be found the type of mosaic in which both mottling and spotting occur on the same leaf. (Fig. 3.) These spots will necessarily persist on the cured leaf.

Another form of injury is the mosaic blister. This form of the disease may occur on leaves having none of the mottling or mosaic pattern shown in Figure 1, but it appears only on plants with top or sucker leaves that manifest these symptoms. It seems to be something like sunburn, as it generally occurs in bands across the most exposed portion of the leaf. (Fig. 4.) This effect suggests that the disease interferes with the ability of the plant to supply water to its leaves. This form of the disease sometimes does considerable damage when infection takes place at topping time or later from suckering the crop. In the present test this form of injury was not common.

The cured tobacco exhibits as its most characteristic mosaic injury a dwarfing. (Fig. 5.) There is also some discoloration, but the most apparent injury to the quality is produced by the spotting of the leaves. (Fig. 6.) This spotting may be the same as that associated with mottling observed on the green leaves, as illustrated by Figure 3, or of the blister form, as shown in Figure 4.

The results presented in Table 2 are quite consistent in showing that the mosaic disease causes marked damage to the yield and quality of tobacco. The severity of the damage is in direct relation to earliness of inoculation following transplanting, the earliest inoculations showing the most damage. Inoculations taking place up to one month after transplanting will cause marked reductions in yield and quality. Infection which takes place at topping time may not produce a significant reduction in yield, but will affect the quality of the crop adversely. The figures presented in Table 2 show as much as 50 per cent reduction in yield and 75 per cent reduction in gross value per acre. For the entire period the average yield is reduced 30 to 35 per cent and the gross value per acre more than 55 per cent for early inoculations. Hence, the reduction in quality of the product is greater than the reduction in yield. This is also illustrated in the last column of Table 2 which shows the average price of the tobacco per 100 pounds.

SUMMARY

The mosaic disease of tobacco is very prevalent in the southern Maryland tobacco district. Experiments were undertaken in 1925 to study the effect of this disease on yield and quality under a given set of conditions.

Three recognizable forms of damage are exhibited by the green tobacco leaves; namely, the ordinary mottling or mosaic form, the form in which the mottling is accompanied by necrotic spotting, and the blister form; which occurs on leaves showing no mottling. The cured leaves from plants affected with mosaic disease exhibit dwarfing with some discoloration but not in the distinct patterns seen on the

FIGURE 3.—Leaf of tobacco, showing mosaic mottling combined with spotting

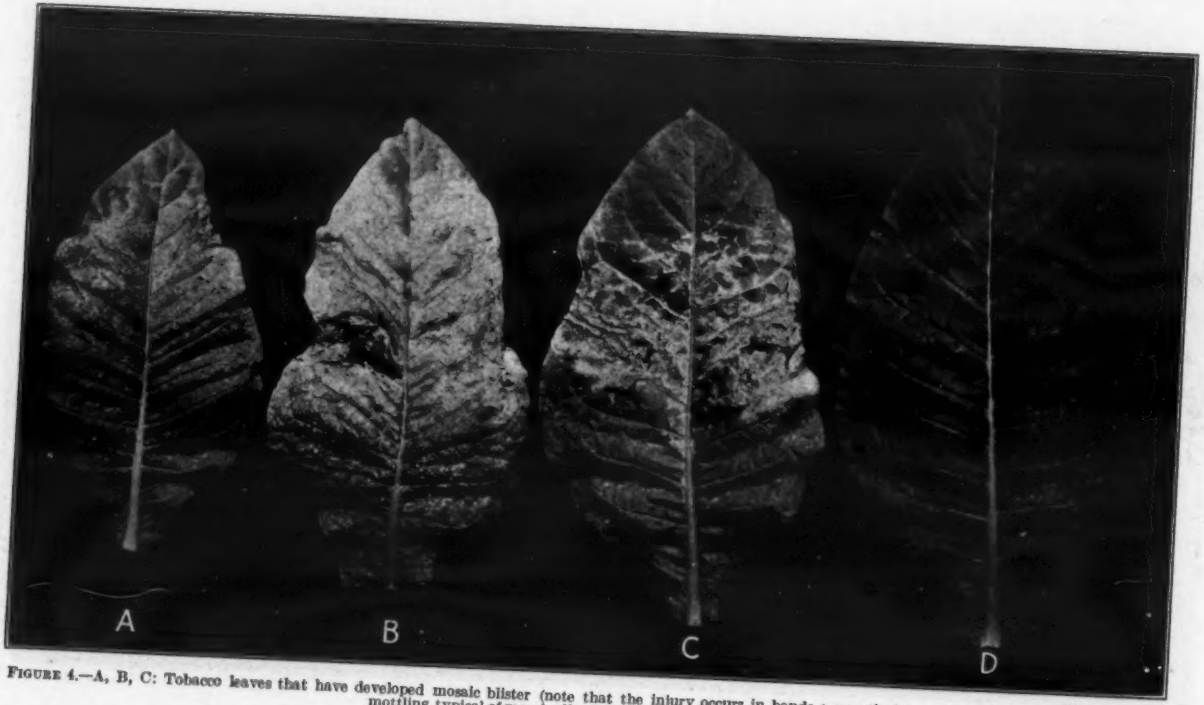

FIGURE 4.—A, B, C: Tobacco leaves that have developed mosaic blister (note that the injury occurs in bands across the leaves, though they do not show the mottling typical of mosaic disease); D, normal tobacco leaf

FIGURE 5.—Bundles of cured tobacco, showing effect of mosaic disease on cured leaf: A, Bundle from diseased plants; B, bundle from healthy plants. Note reduction in size, spotting, and discolorations on A

FIGURE 6.—Leaf of cured tobacco, showing spotting resulting from mosaic disease

green leaves. The most striking effects of the disease on the cured leaf are the spots which are of the same types as those occurring on the green leaves.

The yield and the quality of tobacco are very adversely affected by the disease, especially when infection takes place soon after transplanting. Averages computed for the three years covered by this test indicate that inoculation at transplanting time reduced the yield 30 to 35 per cent and the gross value of the crop per acre more than 55 per cent. When the infection took place one month after transplanting the damage was almost as severe as that caused by inoculation at transplanting time. Inoculation at topping time did not produce a significant reduction in yield, but even at this late date the quality of the crop was lowered by the development of the disease following late inoculation.

A BACTERIAL LEAF SPOT OF HORSE-RADISH CAUSED BY BACTERIUM CAMPESTRE VAR. ARMORACIAE, N. VAR.[1]

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INTRODUCTION

In 1926 several plants of horse-radish (*Armoracia rusticana* Gaertn., Mey. and Schreb.) growing in a greenhouse of the Department of Agriculture in Washington, D. C., developed a serious leaf-spot disease. These plants, with normal and vigorous leaf development, were grown from apparently healthy crowns planted some months before, and they had shown no sign of disease until late summer, when all the leaves were found thickly covered with spots. These particular plants were in the center of the house and partly shaded by cotton, papaya, and orange plants, all of which were free from disease. Some other horse-radish plants in the same house but on a bench where they received more light and air were so slightly infected that it required careful search to find the few spots that were present. Later the infection became more general on the bench plants, but never so heavy as on the partially shaded plants. The spots were full of bacteria, and isolation plates produced numerous colonies of a yellow bacterium with which characteristic lesions have been successfully reproduced on healthy horse-radish leaves. No fungi were found associated with the disease, and there was no trace of vascular infection.

In 1927 the same type of bacterium was isolated from leaf spots on horse-radish grown in Virginia (Arlington Experiment Farm), the District of Columbia (Terra Cotta), Connecticut, Iowa, and Missouri. None of the many naturally infected leaves sent in from these localities have shown any evidence of vascular infection.

In general appearance and growth the organism isolated from the horse-radish leaf spots closely resembled *Bacterium campestre* (Pam.) EFS., which so commonly infects many of the cruciferous plants. Further study proved that in morphological, cultural, and physiological characters it is practically identical with *Bact. campestre* and *Bact. phaseoli* EFS., but it is unlike these organisms in host reactions.

All the available literature on horse-radish diseases and on *Bacterium campestre* and *Bact. phaseoli* has been examined without any mention being found of a bacterial leaf-spot disease of horse-radish.

A root rot of horse-radish which is attributed to a bacillus (unnamed) has been reported from New Jersey several times since 1920 by Poole (*22*, *23*, *24*) and Martin (*16*, *17*).[2] In England a very serious root rot of horse-radish was described in 1909 and attributed by the investigator (*18*) to *Bacterium campestre*. Sorauer (*36*) in 1899 reported a blackening and heart rot of horse-radish roots, but

[1] Received for publication Nov. 17, 1928; issued April, 1929.

[2] Reference is made by number (italic) to "Literature cited," p. 285.

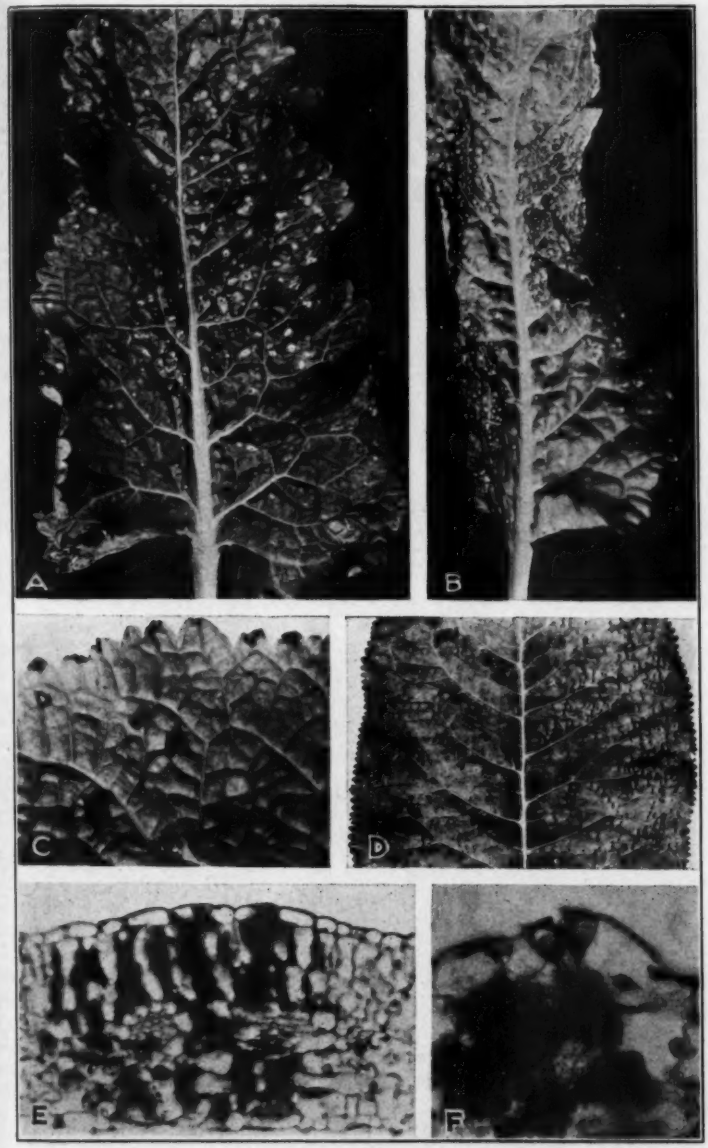
did not determine the cause. Schleyer (*30*) in 1907 observed black points in cross sections of horse-radish roots, but he did not find or describe a causal organism. Smith (*34*) says that he has seen in the United States a disease of horse-radish which causes a crown rot and brown-stained vessels in the root. Faber (*9*) reports a vascular disease of stock (*Matthiola incana*) from which he isolated an organism morphologically and culturally like *Bact. campestre*. Van Hall (*10*) describes a disease of summer stock (*M. annua*) which, according to Faber, is probably due to *Bact. campestre*. Briosi and Pavarino (*1*) have described a disease of stock (*M. annua*) which caused some spotting of the leaves, but the more serious damage was due to vascular infection. *Bact. matthiolae*, the organism described by Briosi and Pavarino as the cause of the disease, is culturally quite unlike *Bact. campestre*.

From Chinese cabbages showing a characteristic vascular infection and consequent wilting and rot of the leaves, Brown and Harvey (*2*) isolated an organism which was similar to *Bacterium campestre*. In addition to the vascular infection, "specking or spotting of the leaf blade may occur." On the Chinese cabbage the leaf spots, which apparently are the least serious phase of the disease, are in appearance not unlike those on horse-radish leaves. Brown and Harvey found that the organism isolated from the Chinese cabbage produced on the common cabbage a vascular infection and wilt similar to that caused by *Bacterium campestre*.

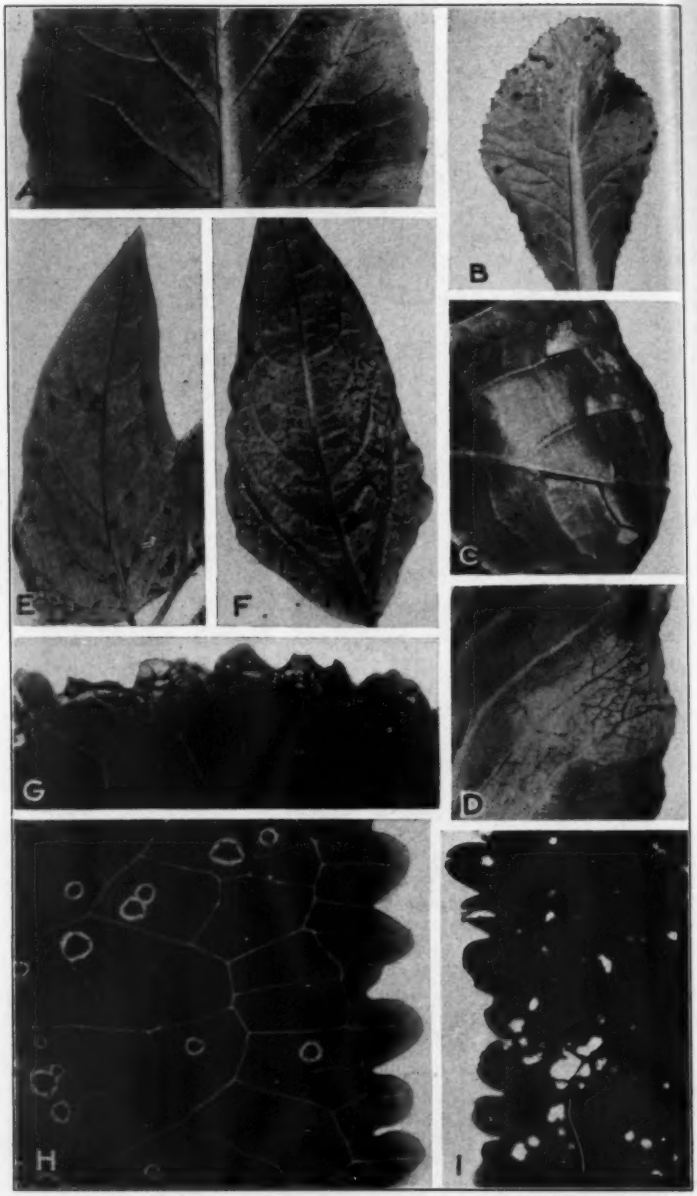
DESCRIPTION OF THE DISEASE

The infected leaves bear numerous circular to angular spots, 1 to 4 mm. in diameter. (Pl. 1, A.) Young spots are uniformly translucent; when older they are more or less opaque, yellowish white to brown, or even black, with a dark, almost black border, which in turn is surrounded by a definite translucent zone. The lesion first appears as a tiny, translucent, pale-green point, visible only by transmitted light. Twelve to twenty-four hours later it is visible by reflected light as a small, dark-green spot. Young lesions are most noticeable on the lower side of the leaf. An infection that might escape casual observation from above would at once attract attention if seen from below. Fairly well isolated lesions attain a diameter of 4 mm., but the average size is 1 to 2 mm. (Pl. 2, H.) No bacterial ooze has been observed on the lesions. When 2 to 3 weeks old the spots have dull, dirty-white to brownish centers with a dark border, beyond which there is a halo of pale green.

By transmitted light the parchmentlike center and the outer translucent zone are separated by the opaque, dark border. Variations, seemingly due to the degree of moisture, often occur; the outer translucent zone may be very narrow or even absent; occasional lesions are uniformly dark, others uniformly pale, and still others mottled with light and dark areas. With age the centers sometimes drop out. The vascular system of the leaf is not affected. Occasionally when a vein is included in a lesion it becomes dark, but the infection has never been observed to spread in the vein beyond the border of the lesion. (Pl. 1, C.) Leaf-margin infections occur, but the lesions remain small, and the infection does not extend into the veins. (Pl. 1, C.) Many leaf margins are entirely free from infec-



Inoculations on horse-radish with *Bacterium campestre armoraciae:* A and B, 20 days after inoculation, × ¾; C, margin of leaf seven weeks after inoculation, × 2; D, right side of leaf inoculated on the upper surface, left side inoculated on the lower surface, × about ½; E, section of leaf five days after inoculation, × 250; F, stomatal infection four days old, × 800. (Photographed by James F. Brewer)



Bacterium campestre armoraciae: A, Cauliflower two weeks after inoculation, slightly enlarged; B, cauliflower two weeks after inoculation, × 1; C, cabbage five weeks after inoculation with *Bact. campestre armoraciae*, × 1; D, cabbage 17 days after inoculation with *Bact. campestre*, × 1, for comparison with A, B, and C; E, Lima bean inoculated with *Bact. phaseoli*, × 2; F, Lima bean inoculated with *Bact. campestre armoraciae*, × 2; G, marginal infection on horse-radish nine weeks after inoculation with *Bact. campestre*, × about 4; H, typical *Bact. campestre armoraciae* lesions on horse-radish 18 days after inoculation, × about 4; I, horse-radish eight weeks after inoculation with *Bact. campestre armoraciae*, × 3. G, H, and I were taken by transmitted light. (Photographed by James F. Brewer)

tion. (Pl. 2, H, I.) Coalescing lesions may cause a general browning and drying of considerable areas of leaf surface, and heavily infected leaves become yellow and die prematurely. (Pl. 1, B.) After reaching the maximum size possible under the conditions, the lesions remain apparently unchanged for weeks, and unless heavily infected the leaf seems not particularly damaged by the parasite. In damp, warm weather new infections continue to appear both on the leaves originally infected and on those newly developed. (Pl. 1, A. B.) No trace of vascular infection has been found in any of the numerous leaves examined.

All parts of the lesions are full of bacteria, and from sections of fresh tissues the bacteria roll out in dense clouds. Fixed and stained sections show that in the early stages of the infection intercellular spaces and also cells that appear intact are filled with bacteria. Later the cell walls break down, and the cavity thus formed is filled with a dense mass of bacteria. A study of leaf sections shows that the infection is mostly, if not always, stomatal. (Pl. 1, E, F.)

ROOT DISEASES OF HORSE-RADISH

Previously and during the course of this investigation two root diseases of horse-radish have been encountered. One causes a soft rot and finally the entire destruction of all tissues except the tough fibers. In early stages of the disease the tissues are dull white to yellowish, spongy, light in weight; cells not separated; cell walls hyaline, later brownish; scanty to no starch in the cells; no odor other than the natural odor of the root. This sort of rot apparently starts at the crown and works downward. In some cases a wall of cork cells limits the rot and the roots partially recover and continue growth from side buds about a hollow or badly split-up crown. In microscopic examinations no organisms have been found except in the advanced stages of the disease. Isolations have given various sorts of organisms, none of them resembling *Bacterium campestre*.

The other type of root rot may be merely a phase of the one just described. Sometimes both kinds occur in the same root. In this disease the fibrovascular tissues are gray-brown to almost black. The tissues are firm; no organism has been found by microscopic examination, and isolations fail to give any organism resembling *Bacterium campestre*. This is probably the disease reported by Sorauer (*36*).

None of the plants with diseased roots, grown in pots in the greenhouse and in a small outdoor bed in Washington, have developed any bacterial leaf spots in the two years they have been under observation.

In cases occasionally seen where the horse-radish leaves are attacked by bacteria of the *Bacterium campestre* type and the roots by some sort of rot, one is forced to consider the possible relation between the disease on the leaf and on the root, the more so because a root rot of horse-radish has been attributed to *Bacterium campestre* by Middleton (*18*), and Pammel (*20*) found it causing a root rot of rutabagas, turnips, and rape. Pammel also mentions the dark fibrovascular bundles and states that soft-rot organisms follow the causal yellow bacteria. If either or both of the horse-radish root diseases observed by the writer should prove to be due to *Bacterium campestre* or a

closely related organism, the failure to isolate any organism from the petioles and midribs of leaves badly infected with the bacterial leaf-spot disease makes it appear that the infection does not reach the roots from the leaves by way of the vascular system.

ISOLATION OF THE ORGANISM

The bacteria are easily isolated from the leaf spots by the usual poured-plate method. The plates usually produced pure cultures of a yellow bacterium which when sprayed on healthy horse-radish leaves produced the typical lesions of the disease. Reisolations were made and infections again obtained.

Although no discoloration was observed in the vascular tissues, microscopic examinations of infected leaves were made, together with cultures from their veins, midribs, and petioles. The results of these examinations and cultures were negative.

INOCULATIONS WITH THE HORSE-RADISH ORGANISM

HORSE-RADISH

The disease is readily reproduced on horse-radish leaves by spraying them with a water suspension of the bacteria or by spreading the bacterial suspension over the leaf with a bit of absorbent cotton. The inoculated plants and uninoculated checks were usually kept in a moist, shaded case for 24 to 36 hours after inoculating. The first signs of infection are visible in 4 to 5 days as minute translucent spots. In 6 to 7 days, small, dark-green spots are found on the lower surfaces of the leaves. Still later the infection becomes visible on the upper sides of the leaves.

No infection resulted from prick inoculations made into the vascular tissues.

In spite of the fact that lesions are at first more distinct on the lower side, it appears that leaves inoculated on the upper surface become more heavily infected than those inoculated on the lower surface. To test this point, some leaves were inoculated on the upper side only and other leaves on the lower side only. In every case many more infections occurred on the leaves inoculated on the upper surface.

Another experiment was then made to determine whether this difference could be due to differences in plants, to the age of the leaf, or to the particular environment of certain leaves. On the selected leaves the right side or half (with the midrib as the dividing line) was inoculated on the upper surface. The other half (left side) was inoculated on the lower surface. These leaves were normal, well-developed blades having the two sides practically equal in area. By using a bit of absorbent cotton the bacterial suspension could be evenly spread over the desired area without contaminating other parts of the same leaf or any adjoining leaves. The plants were kept in a large case where there were no air currents or other disturbances to cause leaf movement and distribution of the infection. The results were even more striking than in the previous experiments. All the leaves (eight) developed numerous lesions on the right side of the midrib and comparatively few on the left side. By count there were seven to eight times more spots on the right sides than on the left sides. (Pl. 1, D.)

The horse-radish has numerous stomata on both sides of the leaves, and examination of the epidermis revealed no apparent differences in the size, structure, or number of the stomata of the upper and lower surfaces. Both sides of the leaf are easily wet with the bacterial suspension and apparently retain the moisture equally well.

CABBAGE AND CAULIFLOWER

Under very favorable conditions, cabbages and cauliflowers inoculated with the horse-radish bacteria developed leaf spots on areas from which the bloom had been wholly or partially removed. The leaves were inoculated by spraying heavily with bacteria in water or by applying the bacterial suspension to the leaf surface with a bit of cotton wool. From a number of such inoculations during the last two years leaf spots have been obtained on only about half of the plants and on only one leaf, or at most on two leaves, of the plant. Parallel inoculations with *Bacterium campestre* resulted in practically 100 per cent of the typical vascular infections characteristic of that organism.

The spots due to the horse-radish bacteria are usually small, pale gray-green, circular, sunken (pl. 2, A, B), and by transmitted light show a translucent halo. With age they become dark gray and dry. Water pores occasionally show signs of infection as tiny black points. In one experiment rather large marginal spots were produced. (Pl. 2, C.) These spots had definite dark borders unlike the indefinite margin of infections due to *Bacterium campestre*. The infection did not progress in the leaf tissue, and the veins in the lesion and surrounding tissue were not darkened.

Microscopic examinations show that the bacteria are usually not very abundant in the lesions on cabbage and cauliflower leaves. In some no bacteria could be found, and isolation of the organism was successful only after repeated trials. This scarcity of bacteria in the lesions suggests that in some cases the damage may be more or less due to physical or chemical causes. The reisolated organism from both cabbage and cauliflower was successfully tested for pathogenicity on horse-radish. In no case was there any discoloration of vascular tissue in the cabbage or cauliflower, and efforts to isolate the bacteria from vascular tissues adjoining leaf spots were not successful.

The bacteria reisolated from cabbage and from cauliflower lesions were again used to inoculate cabbage and cauliflower leaves, but the results did not indicate any increased pathogenicity from passage through these hosts.

In all these inoculation experiments, check inoculations were made on horse-radish leaves, which always developed numerous typical spots.

In addition to the spray inoculations, both cabbages and cauliflowers were heavily inoculated by pricking the bacteria into the vascular tissues of stems, petioles, and leaves. In one case each of cabbage and cauliflower, five months after inoculations were made by pricking the bacteria into stalks just above the petioles, a few dark streaks were found in the stalks near the inoculated areas. (Inoculation wounds still visible.) Adjacent leaves showed no signs of disease. Cultures were made, and from the cauliflower the yellow organism was recovered. Except for this slight evidence no vascular

infections were obtained on cabbages or cauliflowers when inoculated with the horse-radish bacteria.

Check plants of both cabbage and cauliflower of the same age and variety as those inoculated with the horse-radish bacteria, when inoculated with *Bacterium campestre* by pricking, developed the characteristic vascular infection of that organism.

STOCK

Two inoculation experiments with stock (*Matthiola* sp.), in which the bacteria were sprayed and rubbed on the leaves, gave no infections. In the third trial a few pale, irregularly shaped spots appeared. The tissues in the lesions were collapsed and very thin. Under a lens the veinlets showed as dark lines in the pale tissue. The typical yellow bacteria were isolated from the spots. In this third attempt bacteria had also been pricked into the stems. Two and a half months later one of the plants had yellow, sickly looking leaves. Examination showed dark vessels in the stem in the vicinity of the inoculation wounds. In a microscopic examination no bacteria were found, and isolation plates made from the tissues produced only four yellow colonies which in cultural tests proved to be like the organism used to inoculate the plant.

LIMA BEAN

One experiment with Lima beans under favorable conditions (checks were successfully infected with *Bacterium phaseoli*) gave no trace of infection. A second experiment under apparently similar conditions resulted in a number of spots on young leaves not yet fully developed. On the sixth day the spots were mere specks, dark and angular in the center of pale-yellow areas having indefinite margins. When 10 days old they were still small (one-fourth mm. and less), angular, dark reddish brown, and opaque (pl. 2, F); whereas the checks (parallel plants inoculated with *Bact. phaseoli*) had lesions 1 to 1½ mm., dull yellow brown, and very translucent (pl. 2, E).

OTHER PLANTS

Mustard, radish, kale, nasturtium, candytuft, wild cress, squash, poppy, cotton, navy bean, and cowpea were inoculated, but no infections were secured.

INOCULATIONS WITH BACTERIUM CAMPESTRE[1]

HORSE-RADISH

When the leaves of a horse-radish plant are sprayed or rubbed with *Bacterium campestre* and kept very moist for several days lesions sometimes develop on one to three of the leaves. Evidently the bacteria can attack only leaves of a certain age. The lesions are few in comparison to those produced by the horse-radish bacteria and also slower (eight days) in developing. When first visible they are similar to lesions caused by the horse-radish bacteria; when older they may be entirely like the usual horse-radish spots, or they may be uniformly opaque, dark brown to black, sunken, alike on both sides of the leaf,

[1] Three strains of *Bacteria campestre* were used: A, Received in 1926 from Wisconsin, age unknown; B, a subculture resulting from infection of cabbage with A; C, isolated in 1927 from infected cabbage sent from Wisconsin. All 3 strains produced in cabbages and cauliflowers the characteristic vascular disease known as black rot.

and with no translucent border or only a trace of it. Leaf-margin infections were good in one case. (Pl. 2, G.) In most of the inoculation trials no infection occurred.

Check plants inoculated with the horse-radish organism never failed to give large numbers of lesions on all but the very youngest leaves. Leaves were inoculated by pricking *Bacterium campestre* into the vascular tissues of midribs and petioles. No infection resulted. Smith (*34*) inoculated horse-radish with *Bact. campestre* but obtained no infections.

CABBAGE AND CAULIFLOWER

Cabbage and cauliflower plants of the same age and variety as those inoculated with the horse-radish bacteria were inoculated with *Bacterium campestre*, and the typical "black rot" vascular infection resulted. The inoculations were made by pricking the bacteria into the vascular tissues at the base of the petioles and on midribs and also by spraying the leaves with bacteria in water. In the spray inoculations the infection started in the water pores and spread into and darkened the veins. (Pl. 2, D.) The leaves gradually yellowed and fell off. No leaf spots occurred in these experiments unless the bloom had been removed from the leaves. In such cases leaf spots developed which looked quite like those produced by the horse-radish bacteria under similar severe inoculating conditions.

The waxy bloom on the leaves of these plants prevents wetting, and a fine spray, even if it remains on the leaf surface, may not be in direct contact with the epidermis and the stomatal cells. The large water pores on the leaf margin are usually the only places where the bacteria in water can gain entrance to the interior of the leaf. Russell (*28*) reports that no leaf spots are caused by spray inoculations of *Bacterium campestre* unless the leaves are injured. Clayton (*4*) reports lesions due to *Bact. campestre* occurring in the field directly through the lower leaf surfaces of cauliflower, Brussels sprouts, and cabbage. Samuel (*29*) describes nontypical *Bact. campestre* lesions on cauliflower in the form of small black leaf spots. He considers this type of infection as probably due to unusual weather conditions.

LIMA BEAN

Leaves of Lima bean were inoculated with *Bacterium campestre* in six different experiments. No infections were obtained. (These beans, Fordhook variety, were very susceptible to *Bact. phaseoli*.)

INOCULATIONS WITH BACTERIUM PHASEOLI[4]

Bacterium phaseoli, the cause of a leaf spot of beans, is morphologically and culturally almost identical with *Bact. campestre* and the horse-radish leaf-spot bacteria. In two different experiments horse-radish leaves were inoculated by spraying with *Bact. phaseoli* suspended in water. The plants were kept in a moist case for three days. In both experiments fairly good infections were obtained. The lesions were first visible on the seventh day, later becoming quite definite, being in character like those produced by the horse-radish bacteria. They were somewhat slow in growth, however, and new

[4] Two cultures were used—one isolated in 1926, the other in 1927. Both were obtained from Miss Florence Hedges.

infections did not occur as is the case when the infection is due to the horse-radish bacteria. One plant, kept unusually moist, 19 days after inoculation, had lesions 1 to 2½ mm. in diameter, but no new lesions. Lima beans and cowpeas inoculated at the same time with *Bact. phaseoli*, developed heavy infections first visible on the fourth day after inoculation.

In five different experiments, leaves of growing cabbages were inoculated with *Bacterium phaseoli*. Some of the plants were young, having 6 to 10 leaves; others were beginning to form heads. Bacterial suspensions were sprayed on the leaves, and bacteria direct from the cultures were spread over the leaves. The inoculated plants were kept moist for periods varying from three to seven days. Not a trace of infection resulted.

CULTURAL CHARACTERS OF THE HORSE-RADISH ORGANISM[5]

PRELIMINARY STUDY

Preliminary study had demonstrated that the bacteria causing leaf spot of horse-radish have characters similar to several others of the already rather large group of yellow plant pathogenes. For this reason, in practically all of the cultural work, parallel cultures of *Bacterium campestre*[6] were made for comparison, and in a number of media the horse-radish organism was compared in parallel cultures of *Bact. phaseoli*, *Bact. phaseoli sojense*, *Bact. malvacearum*, *Bact. cucurbitae*, *Bact. stewarti*, and *Bact. hyacinthi*.

In the rather extensive list of publications relative to *Bacterium campestre*, only three papers have been found—Harding (*11*), Russel (*28*), and Smith (*34*)—which give detailed descriptions of the morphological and cultural characters of the organism. These investigators found that cultures of different origins and different ages often varied more or less in cultural characters and in virulence. Brown and Harvey (*2*) came to the same conclusion.

Dufrenoy and Szymanek (*7*) describe a cauliflower disease that occurs in France and has symptoms like those produced by *Bacterium campestre* and a causal organism similar to but not identical with *Bact. campestre*. Paine and Nirula (*19*) report a root rot of swedes (rutabagas) and turnips having general symptoms unlike those of *Bact. campestre*, but a causal organism similar to *Bact. campestre*. They also state that their organism corresponds exactly with the one isolated in France from cauliflower by Dufrenoy and Szymanek (1 to 4 flagella; faintly chromogenic; colonies on agar, white with yellow papilla; gelatin liquefied rapidly; nitrate reduced; diastatic action decided but moderate; distinct alkaline reaction from glucose sucrose, and lactose). These authors are inclined to view their organism as a saltant, a biological strain of *Bact. campestre*.

In the present study no variations other than the rough colonies (p. 277) have been observed in the several strains of the horse-radish bacteria, but these are all of recent isolation and may show variations after a longer period in artificial culture. In general, they grow more vigorously in culture than either *Bacterium campestre* or *Bact. phaseoli*.

[5] Detailed descriptions of *Bacterium campestre* are given by Harding (*11*), Russel (*28*), and Smith (*34*). These publications may not be available to all workers. Other published descriptions of *Bact. campestre* are lacking in various ways, so it seems advisable to give a fairly detailed description of *Bact. campestre* var. *armoraciae*. This description is mostly in tabular form (see Table 1).

[6] See footnote 3, page 274.

Unless otherwise stated, the cultures were grown at room temperature. Beef medium was made from fresh beef infusion and had a pH value of 7.0. Colors are according to Ridgway (*27*).

BEEF-AGAR COLONIES

Small white colonies are visible in two days. The color soon becomes pale yellow (massicot yellow) and later amber or wax yellow. They are round, flat, smooth, shining, translucent, with entire margins. Typical colonies are uniform in structure. Under the microscope they are finely granular, with a few coarse granules in the center. Colonies frequently show interior markings, as delicate striae, usually concentric, occasionally radial in arrangement, or a mottled, loose, almost lacy structure. Some colonies have a wide border or zone less dense than the center. The markings gradually disappear. Well-isolated colonies are 6 mm. in diameter when 10 days old. In texture the growth is smooth and soft. Buried colonies are oval to spindle shaped. When 2 to 3 weeks old there is a renewal of growth in the form of small circular colonies breaking through the original growth and also wedge-shaped growths at the margin. The new growth is lighter in color than the old and often exceeds the original colony in area. This renewal of growth is much more vigorous and extensive in the horse-radish organism than in *Bacterium campestre*. Both surface and buried colonies are usually somewhat brighter yellow and more transparent than colonies of *Bact. campestre* developed at the same time and under identical conditions.

ROUGH COLONIES

Rough-surfaced colonies appear occasionally in most of the isolation plates made directly from leaf spots, and sometimes every colony in a set of plates has the atypical structure. These colonies are smaller in size and brighter yellow than the normal colonies and have from one to several distinct papillae, or convolutions, on the elevated surface, which give them the appearance of miniature raspberries. They are roughly circular; margins irregularly lobed; growth thick, opaque, piled up in contrast to the flat, translucent, normal type of colony. If growing conditions are favorable, well-isolated rough colonies become smooth in 10 to 14 days, but the interior retains various irregular markings, these most often as radiating ridges. With age and drying the rough surface sometimes reappears. In texture the rough colonies are dense and firm, not viscid, but cohering so firmly that in making transfers the whole colony is picked up by the needle. On most culture media the growth is brighter yellow and denser in texture than growth from normal colonies. The surface is often dry and granular in appearance. On beef-agar slants the growth is firmly attached to or incorporated with the surface of the agar and is not easily transferred. Beef broth clouds less readily and has a tendency to form pseudozoogloeae, and milk cultures produce less tyrosine than the normal smooth growth.

Single, well-isolated rough colonies, when replated to test the permanency of the rough character, gave varied results. Sometimes all the colonies obtained from a single rough one would be rough, another would produce only smooth colonies, while others gave a mixture of rough and smooth colonies.

TABLE 1.—*Morphological, cultural, and physiological comparisons of Bacterium campestre armoraciae, Bact. campestre, and Bact. phaseoli*

[*Abbreviations of names of investigators.*—Burk.=W. H. Burkholder; Clay.=E. E. Clayton; Doidge=Ethel M. Doidge; Edg.=C. W. Edgerton; EFS.=Erwin F. Smith; Hard.=H. A. Harding; Faber=F. C. von Faber; F. H.=Florence Hedges; L. McC.=Lucia McCulloch; Manns=T. F. Manns; Pam.=L. H. Pammel; Q. and F.=Agnes Quirk and Edna Fawcett; Rapp=C. W. Rapp; Sharp=C. G. Sharp; Wolf=Frederick A. Wolf]

Specifications	Bacterium campestre armoraciae, n. var.	Bacterium campestre (Pam.) EFS.	Bacterium phaseoli EFS.
Index number	211.2222512	211.2222512. (L. McC.) 211.3332513. (EFS. (*54*), Hard. (*11*).)	211.2222512. (F. H. (*13*).)
Host and general effect	Horse-radish leaves; definite, distinct spots in leaf parenchyma; no wilting; no vascular infection.	Cabbage, cauliflower, and other crucifers; vascular infection, causing wilting and dropping of leaves.	Beans (bush and Lima); primarily a leaf-parenchyma infection. Vascular system sometimes infected. (F. H. (*14*) Burk. (*3*).)
Effect on inoculated horse-radish.	Numerous definite spots develop in the leaf parenchyma; infection through stomata; little or no ooze from the lesions; lesions not shining when dry; infection continues to spread in the form of spots on the same leaf and to other leaves; no trace of vascular infection; no wilt.	Occasionally, and under conditions very favorable for the bacteria, a few leaf spots develop; these are similar to those produced by the horse-radish organism. (L. McC.) Horse-radish was not infected by *Bact. campestre*. (EFS. (*54*).)	Results of inoculation like those from inoculation, with *Bact. campestre*. (L. McC.)
Effect on inoculated cabbage and cauliflower.	Under conditions very favorable for infection, spray inoculations sometimes produce leaf spots comparatively few in number, small in size, and unlike *Bact. campestre* lesions. One out of many prick inoculations developed after several weeks a doubtful vascular infection.	Typical vascular infection, with consequent yellowing, wilting, and death of the leaves. If the waxy bloom is removed from the leaves, spray inoculations sometimes result in definite, small leaf spots. (L. McC.) Leaf spots result only when leaves are rubbed or wounded. (Russell (*28*).) Leaf spots occur under some natural conditions. (Clay. (*4*).)	In five different experiments no trace of infection was secured on cabbage or cauliflower even under most favorable conditions. (L. McC.) No success in infecting cabbage with *Bact. phaseoli*. (EFS. (*52, 55*).) No infection obtained on cabbage. (Johnston.[a])
Effect on inoculated beans (bush and Lima).	Very small, opaque spots, quite unlike *Bact. phaseoli* lesions, are sometimes produced.	Repeated inoculations on bean failed to give infections. (EFS. (*52*).) In six different experiments no trace of infection. (L. McC.)	Typical infections easily obtained. (L. McC.)
Effect on inoculated stock (Matthiola).	A few, but definite, leaf spots and in one case a possible vascular infection.	Vascular infection. (Faber (*9*).)	
Effect on inoculated turnip		Veins blackened and tissues killed. (Johnston [a].)	No trace of infection. (Johnston [a].)
Morphology	On beef agar, single rods, 0.7 to 2 by 0.3 to 0.5μ; some paired, no chains observed; many irregular forms. On potato or media with sugar, the average size is larger than on beef agar; long chains occur; forms are regular, 0.7 to 2.7 by 0.3 to 0.7μ Single polar flagellum. Distinct capsule.	In parallel cultures, like *armoraciae*. (L. McC.) Rod shaped, singly, in pairs, or fours; often irregular in form: 0.7 to 3 by 0.4 to 0.5μ. (EFS. (*54*).) 1.87 to 3 by 0.37μ. (Pam. (*21*).) 0.7 to 3 by 0.4 to 0.5μ. (Doidge (*5*).) 1.0 to 2 by 0.4 to 0.6μ. (Hard. (*11*).) Single polar. (EFS (*54*), Doidge (*5*).)	In parallel cultures, like *armoraciae* except for greater extremes in size; on beef, 0.5 to 2.7 by 0.3 to 0.6μ; on potato and sugar media, 0.5 to 3 by 0.3 to 0.8μ. (L. McC.) Rods, single, paired, and in chains. (EFS. (*55*), Wolf (*57*).) 1.3 to 2.0 by 0.6 to 0.7μ. (Wolf (*57*).) 0.5 to 0.9 by 0.2 to 0.5μ. (Rapp (*56*).)

	No spores. Gram-negative. Not acid-fast.	Distinct capsule. (L. McC.) No capsule. (Doidge (5), Hard (11).) No spores. (Doidge (5).) Gram-negative. (Hard. (11).) Not acid-fast. (L. McC.)	Single polar. (EFS. (33, 35), Doidge (6), Rapp (26), Wolf (37).) Distinct capsule. (L. McC.) No capsules observed. (EFS. (35), Rapp (26), Wolf (37).) No spores observed. (EFS. (33, 35), Rapp (26), Wolf (37).) Gram-negative. (EFS. (35), F. H. (14), Rapp (26) Wolf (37).) Not acid-fast. (Rapp (26).)
Colonies on beef-agar plates	White, changing to pale yellow, then deeper yellow; uniform structure, only occasionally ringed; translucent, becoming transparent; in parallel cultures, usually brighter and clearer yellow than *Bact. campestre*. (Beef-infusion agar used in all experiments by L. McC.)	Both surface and buried colonies usually less yellow and less transparent than *armoraciae;* more likely to have ringed structure. (L.McC.) Pale yellow, deepening with age. (EFS. (34).)	Pale yellow, deepening to wax. (Rapp (26).) Pale to deeper yellow. (EFS. (34).) Often pale ringed. (EFS. (35).) Plainly ringed in 10 days. (Rapp (26).)
Beef-agar stabs	Surface growth seldom reaches wall of tube; a trace of growth at first in the upper part of the stab; white, chemical film over surface not covered by the bacterial growth.	Like *armoraciae*. (L. McC.)	Like *armoraciae*. (L. McC.) Never much growth at base of stab. (F. H. (15).)
Beef-agar slants	Smooth, becoming slightly contoured and transparent; apricot color, deeper yellow than in plates; growth sometimes slightly viscid.	Like *armoraciae* except less transparent and slightly less yellow. (L. McC.)	Like *armoraciae* except that the sediment in the V is stronger yellow and when 3 weeks old the whole culture is brighter yellow. (L. McC.) Moderate, pale yellow; sometimes slightly viscid. (F. H. (15).)
	White chemical film	White chemical film. (L. McC.)	White chemical film. (L. McC., Rapp (26).)
Beef bouillon	Clouds thinly in 24 hours; growth best at the top; if undisturbed, thin, ragged pellicles and rims form; sediment yellow, translucent, slightly viscid, rises in a spiral when rotated.	Like *armoraciae*. (L. McC.) No true pellicle or rim; yellow, granular precipitate. (Hard. (11).)	Like *armoraciae*. (L. McC.) Surface ring nearly white. (Rapp (26).) In 3 to 4 weeks, yellowish rim; partial to complete pellicle; viscid, yellow precipitate. (F.H. (15).)
Whey agar	Yellow color of growth less bright than on parallel cultures of *Bact. campestre*.	Strong yellow color; deeper yellow than with the horse-radish organism. (L. McC.)	Copious, primuline yellow in 9 days. (F. H. (15).)
Beef gelatin	Beef-infusion gelatin at 18° C. liquefaction begins promptly but requires 2 to 3 months to complete; liquid clear; sediment, bright yellow (apricot); no rim; no pellicle. Beef-extract gelatin at 18° C.; liquefaction more rapid than in the beef-infusion gelatin; liquid cloudy; sediment dirty, yellowish brown; thin rims and pellicles.	No liquefaction. (Pam. (21).) Liquefaction slow. (EFS (32), Hard. (11), Doidge (5).). Liquid clear, copious precipitate. (Hard. (11).).	Liquefaction prompt. (F. H. (15).) Liquefaction slow. (EFS. (34), Rapp (26), Doidge (6), Wolf (37).) Liquid cloudy. (Rapp (26).) Liquefaction rapid. (Sharp (31).)

* Johnston, J. R. Unpublished notes of work done in 1906.

TABLE 1.—*Morphological, cultural, and physiological comparisons of Bacterium campestre armoraciae, Bact. campestre, and Bact. phaseoli*—Continued

Specifications	Bacterium campestre armoraciae, n. var.	Bacterium campestre (Pam.) EFS.	Bacterium phaseoli EFS.
Blood serum (Loeffler's No. 8).	At 18° C., bright-yellow growth; liquefaction begins promptly but requires 4 weeks to change all the medium to a transparent, amber-colored liquid; tyrosine crystals form.	No liquefaction. (Pam. (*21*).) Slow liquefaction. (EFS. (*34*), Doidge (*6*).) Liquid part, pale brownish. (EFS. (*32*).)	Liquefaction better than in *Bact. campestre*. (EFS. (*35*).) Liquefaction begins in 6 to 9 days, not complete in 2½ months. (F. H. (*15*).) In 20 days liquefaction less than in *Bact. campestre*. (EFS. (*34*).)
Milk	At 28° C., rapid clearing complete in 2 to 4 days; in 2 weeks translucent throughout with small amount of submerged translucent material; narrow yellow rims; moderate yellow sediment. In 16 days the pH changed from 5.9 to 6.4; later to 7.0. After 8 weeks the cultures are like *Bact. campestre* and *Bact. phaseoli*. Tyrosine crystals form.	At 28° C., slow clearing; in 2 weeks upper half of milk transparent; lower half soft, opaque curd. (L. McC.) In 16 days the pH changed from 5.9 to 6.6; later 6.8 to 7.1. (L. McC.) No acid; casein settles slowly. After some weeks is partially redissolved. (EFS. (*34*).) No acid; casein sometimes peptonized without apparent curdling. (Hard. (*11*).) Tyrosine crystals form. (EFS. (*34*), L. McC.)	At 28° C., slow clearing, usually like *Bact. campestre* but sometimes slower; one strain cleared in 7 days. (L. McC.) In 16 days the pH changed from 5.9 to 6.4; later 6.5 to 7.0. (L. McC.) No acid; casein thrown down slowly. (EFS. (*35*), Rapp (*26*), Doidge (*6*).) Like *Bact. campestre*. (EFS. (*35*).) Tyrosine crystals form. (EFS. (*35*), L. McC.)
Litmus milk	Not blued; reduction of litmus sometimes complete in 6 days, sometimes not entirely reduced in 3 weeks or more; color returns rather promptly; after 8 weeks the appearance is practically the same as *Bact. campestre* and *Bact. phaseoli* cultures of the same age.	Blued. (EFS. (*35*), Doidge (5), L. McC.) The blue color slowly deepens for 8 to 10 days; still blue in 20 days; later the litmus is more or less reduced. (EFS. (*35*).) Most of litmus reduced in 25 days; less rapid reduction than in var. *armoraciae*. (L. McC.)	Blued; reduction less and slower than in *Bact. campestre*. (L. McC.) Like *Bact. campestre*. (EFS. (*35*).) No reduction of litmus in 25 days. (Sharp (*31*).) Reduction begining in 4 to 16 days, complete in 5 to 19 days. Occasionally not complete in 3 weeks. (F. H. (*15*).)
Methylene blue milk	All color reduced in 4 days; did not return in 4 months.		All color disappears in 1 to 2 days. (F. H. (*15*).)
Methylene blue in Dunham's solution.	Practically complete reduction of color in 10 days; color returns slowly.	Reduction slightly slower than in *armoraciae*. (L. McC.) Marked reduction, one-half reduced in 9 days; in 56 days green; precipitate not stained. (EFS. (*35*).)	Reduction slower and less complete than in *Bact. campestre*, but color returns more rapidly. (L. McC.)
Dunham's solution plus rosalic acid.		6 days, no reddening; 9 days, distinct pink; 16 days, geranium red; 21 days, geranium red; 37 days, poppy red. (EFS. (*35*, *34*).)	
Dunham's solution plus indigo carmine.		15 days, greenish blue; 20 days, very pale green; 24 days, color gone; remained reduced. (EFS. (*35*).)	
Beef agar plus Congo red	Bacterial growth becomes red	Bacterial growth red, as in *armoraciae*. (L. McC.)	Bacterial growth much as in *Bact. campestre*, but often orange red. (L. McC.)

Toleration of NaCl in beef bouillon.	Growth within 48 hours in 2, 3, and 4 per cent; growth in 14 days in 5 per cent.	Like *armoraciae*. (L. McC.) Less sensitive to salt than *Bact. phaseoli*. (EFS. (*54*).)	Growth limit in 3 per cent (17 days' observation). (L. McC.) Growth limit 4 per cent. (F. H. (*15*).)
Beef broth over chloroform	Good growth in 48 hours if rather heavily inoculated; no growth if lightly inoculated.	Good growth if rather heavily inoculated; no growth if lightly inoculated. (L. McC.) No growth. (EFS. (*33*, *34*).)	No growth even when heavily inoculated. (L. McC.) Slow, long-continued growth, but with much difficulty in getting started. (EFS. (*33*).)
Reaction acid and to alkali.	In beef-infusion broth: pH range, 5.3 to 9.1; pH optimum, 7.2 to 7.4. In beef-extract broth: pH range, 5.1 to 9.6; pH optimum, 6.0 to 6.6.	In beef-infusion broth: Growth in −40[b] in 2 to 5 days. (EFS. (*33*).) Growth in +30[b] in 1 to 2 days. (EFS. (*33*, *34*).) pH range: 8.8 to 6.1 (−10 to +26).[b] (Q. and F. (*25*).)	No growth in nutrient broth containing more than 3 per cent acid. (Rapp (*26*).) In beef-infusion broth: Range, 8.4 to 5.7 (−3 to +28).[b] (Q. and F. (*25*).)
Potato cylinders (moist)	Pale yellow, rapidly changing to wax yellow; copious, smooth, shining growth, covering the potato and invading the liquid; in age various brownish colors; small golden-brown crystals often abundant.	Like *armoraciae*. (L. McC.) Copious, yellow slime. (EFS. (*33*, *34*).) Wet, shining yellow. (Doidge (*5*).) Light yellow, changing to cadmium yellow. (Russell (*28*).)	Like *armoraciae*. (L. McC.) Like *Bact. campestre*. (EFS. (*28*), Doidge (*6*), F. H. (*13*).)
Cohn's solution	No growth	Growth evident in only 11 out of over 50 strains. (Hard. (*11*).) Usually no growth. (EFS. (*34*).)	Feeble growth. (EFS. (*35*).)
Fermi's solution	Very moderate, uniform clouding, milky; scanty translucent sediment.	Scanty growth, thin clouding, no pellicle; scanty precipitate. (EFS. (*34*).)	
Uschinsky's solution	Thin, uniform clouding in 2 weeks; thin, yellow rims; moderate sediment; in 3 weeks moderate growth, rather heavy at surface as small pseudozoogloeae; no fluorescence.	Feeble, retarded growth; no pellicle. (EFS. (*33*).) Growth evident. (Hard. (*11*).)	Feeble growth; no pellicle; yellower and rather better growth than in *Bact. campestre*. (EFS. (*35*).) Faint to moderate clouding. (F. H. (*13*).) Growth slow or not at all. (Doidge (*6*).)
Temperature relations	Optimum, 28° C. to 30° C.; maximum, 36° C.; minimum, below 2° C.; thermal death point, about 51° C.	Optimum, 30° C. or thereabouts; maximum, 38° C. to 39° C.; minimum, 5° C. or thereabouts; thermal death point, about 51° C. (EFS. (*34*).) Maximum, feeble or not at all at 37° C. to 38° C.; minimum, below 7° C.; thermal death point, 51.5° C. (EFS. (*33*).) Thermal death point, 46° C. (Manns (*15*).) Optimum, 30° C. to 32° C. (L. McC.)	Thermal death point: Approximately 49° C. (EFS. (*32*).) 49.5° C. (EFS. (*35*).) Approximately 50° C. (EFS. (*35*).) 48° C. (Manns (*15*).) About 50° C. (Rapp (*26*).) 50° C. (Wolf (*37*).) 49° C. to 50° C. (Doidge (*6*).) Grows well between 25° C. and 30° C. (Doidge (*6*).)
Chromogenesis	Yellow, not photogenic, not fluorescent; white to pale yellow, becoming wax to apricot yellow on beef media; on potato, pale yellow becoming wax yellow and when old various shades of brown.	Color characters as in *armoraciae*. (L. McC.) Generally wax yellow; paler than *Bact. phaseoli* on beef-extract agar; in 6 to 8 weeks stained radish, rutabaga, and turnip cultures various shades of brown—raw sienna to mummy brown. (EFS. (*33*, *34*).) Yellow on all media. (Doidge (*5*).)	Color characters as in *armoraciae;* sometimes brighter yellow than either *Bact. campestre* or *armoraciae*. (L. McC.) Wax yellow to chrome; paler than *Bact. campestre* on nutrient starch jelly; on turnip and radish cultures no brown pigment. (EFS. (*33*).)

[b] Fuller's scale.

TABLE 1.—*Morphological, cultural, and physiological comparisons of Bacterium campestre armoraciae, Bact. campestre, and Bact. phaseoli*—Continued

Specifications	Bacterium campestre armoraciae, n. var.	Bacterium campestre (Pam.) EFS.	Bacterium phaseoli EFS.
Production of indol	Small quantities produced in Dunham's solution, by Ehrlich's and also Salkowski's tests; *Bacillus coli* as check.	Indol formed. (EFS. (*33*, *34*), Hard. (*11*), Doidge (*6*).)	No indol found in Uschinsky plus peptone. (F. H. (*15*).) Indol produced. (Doidge (*6*).) Negative. (Rapp (*26*), Wolf (*37*).)
Production of hydrogen sulphide.	Moderate production in beef agar plus basic lead acetate.	Less evidence of H_2S in basic lead acetate agar than in *armoraciae*. (L. McC.) Coconut, radish, and turnip cultures, browned strips of paper impregnated with lead acetate. (EFS. (*33*).) Occasionally formed. (EFS. (*34*).)	Less evidence of H_2S in basic lead acetate agar than *Bact. campestre*. (L. McC.) Produced. (EFS. (*33*).)
Production of ammonia	Moderate production in beef gelatin, beef broth, and potato cultures.	Ammonia produced. Hard. (*11*).)	Ammonia produced from beef broth. (F. H. (*15*).) Produced. (Wolf (*37*).)
Relation to oxygen	Aerobic; tested in fermentation tubes with various media suitable for growth and also in shake-agar cultures.	Aerobic; tested in fermentation tubes with various media. (EFS. (*34*), Doidge (*6*), Hard. (*11*).)	Aerobic. (EFS. (*33*), Wolf (*37*), Doidge (*6*), Rapp (*26*).) Faint clouding in closed ends (fermentation on tubes with 1 per cent lactose in 1 per cent peptone) in 7 days. (F. H. (*15*).)
Diastatic action	Strong; starch-agar plates on fifth day had band 20 to 25 mm. wide free from starch. All starch reduced in potato cylinder cultures.	Same as *armoraciae*. (L. McC.) Strong. (Hard. (*11*).) All starch reduced in potato cylinder cultures. (EFS. (*33*), L. McC.) On nutrient starch jelly in 7 days, considerable starch converted. (EFS. (*33*).)	Good but less than in *Bact. campestre;* in 5 day. the starch-free band was only 14 to 15 mm. wide (L. McC.) Strong starch-destroying action. (EFS. (*33*), F. H. (*15*), Rapp (*26*), Doidge (*6*), Sharp (*31*), Wolf (*37*).) Starch reduced in potato cylinder cultures as by *Bact. campestre*. (EFS. (*33*).) On nutrient starch jelly less starch converted in 7 days than by *Bact. campestre*. (EFS. (*33*).)
Nitrates	Nitrate not reduced; no gas formed	Nitrate not reduced. (EFS. (*33*, *34*), Hard. (*11*), Doidge (*6*), LMcC.)	Nitrate not reduced. (EFS. (*33*, *35*), Doidge (*6*), Wolf (*37*), Rapp (*26*).)
Fermentation	With a beef-medium (extract or infusion) base, plus the carbohydrate to be tested and bromcresol purple as the indicator, dextrose, lactose, saccharose, glycerin, maltose, mannit, and levulose, gave no acid reaction; galactose gave a slight acid reaction. With a synthetic medium [a] base, all of the above carbohydrates gave distinct acid reactions; the strongest reactions were from dex-	With a beef-medium base, various workers report no acid from one or more of the following: Dextrose, lactose, saccharose, glycerin, maltose, mannit, galactose, levulose, and dextrin. (EFS. (*34*), Hard. (*11*), Doidge (*6*), L. McC.) With the synthetic medium [a] base, dextrose, lactose, saccharose, glycerin, and mannit gave acid reactions equal to that from glycerin in	With a beef-medium base, no acid from any of the ordinary sugars. (EFS. (*32*).) Dextrose and saccharose produced acid slowly. (EFS. (*33*).) No acid from dextrose, lactose, saccharose, glycerin. (F. H. (*14*), Wolf (*37*).) No acid from maltose, galactose, manitol, arabinose, xylose, rhamnose, dextrin, salicin, and inulin. (Wolf (*37*).)

	trose, saccharose, and galactose; moderate reaction from maltose, mannit, and levulose; rather slight reaction from glycerin. No gas from any carbohydrate tested; no clouding in closed arm of fermentation tubes.	the horse-radish bacteria cultures; maltose gave no acid reaction. (L. McC.) The various workers report no gas; no clouding in the closed arm of fermentation tubes.	No acid produced in sugar broths. (Doidge (6).) From dextrose, saccharose, and maltose, little change in 30 days; lactose, pH 7.1 changed to 7.6 in 30 days; levulose, pH 6.2 changed to 6.8 in 30 days; galactose produced acid. (Sharp (51).) With the synthetic medium [a] base, dextrose, lactose, saccharose, glycerin, maltose, levulose, and galactose produced acid. (F. H., unpublished notes.) The various workers report no gas; no clouding in the closed arm of fermentation tubes.
Beef-extract agar plus sugar:			
9 per cent dextrose		Growth not retarded. Better than in plain agar. (EFS. (55).)	Like *Bact. campestre*. (EFS. (55).)
17 per cent dextrose		Growth retarded. (EFS. (55).)	Growth retarded but in 6 days one-half more growth than in *Bact. campestre*. (EFS. (55).)
23 per cent dextrose		First and second experiments, growth seriously retarded. (EFS. (55).)	First experiment, growth prevented; second experiment, growth retarded. (EFS. (55).)
9 per cent levulose		Slight growth. (EFS. (55).)	No growth. (EFS. (55).)
23 per cent saccharose		Growth not retarded. (EFS. (55).)	Growth not retarded; better than in *Bact. campestre*. (EFS. (55).)
Starch jelly plus glycerin		Growth retarded, but in 24 days copious bright yellow. (EFS. (55).)	Growth retarded; in 24 days much less growth than in *Bact. campestre* and no distinct yellow color. (EFS. (55).)
Peptone 4 per cent, maltose 4 per cent in distilled water.		Fluid browned. (EFS. (55).)	Fluid not browned. (EFS. (55).)
Vitality	Beef-agar cultures 14 months old still alive; temperature 14° C. to 16° C.	Alive in agar cultures after 17½ months at 5° C. to 16° C. (EFS. (53, 54).)	Under similar conditions dead in one-half month (EFS. (55).)
Desiccation	Beef-broth cultures 48 hours old spread on cover glasses and dried at room temperature; nearly all organisms were dead in 3 days; a few survived 20 days, with vitality much reduced.	Alive after 34 days' drying; covers made from potato cultures, also from beef broth. (EFS. (53, 54).) 45 hours' drying at 29° C.; killed all the organisms. (Hard. (11).) Some survived 10 days' drying on cover glasses. (Hard. (11).)	After 27 days' drying 3 out of 9 covers made from potato cultures were alive; none out of 12 covers from beef broth were alive; seems to be less resistant to dry air than *Bact. campestre*. (EFS. (55).) Alive after 70 days on glass covers. (Rapp (56).) Alive after 18 days on glass covers. (Wolf (57).) Alive for over 200 days when dried on glass cover slips. (Edg. (5).)
Effect of sunlight	Killed by 10 minutes' exposure to sunlight	95 per cent killed in 30 minutes; 98 per cent killed in 45 minutes. (EFS. (55).) Killed in 30 minutes. (Hard. (11).)	All killed in 45 minutes. (EFS. (55).) Not all killed in 30 minutes. (EFS. (54).) All killed in 30 minutes. (Rapp (56).)
Serological relationship [b]			

[a] $NH_4H_2PO_4$, 1 gm.; KCl, 0.2 gm.; agar, 15 gm.; water, 1,000 c. c.

[b] In January, 1927, cultures of the horse-radish bacteria were sent to George K. K. Link, with other cultures (bacteria). In a letter to E. F. Smith, May 16, 1927, Doctor Link states: "Very clearly it [the horse-radish organism] is serologically closely related to *Bact. campestre*. It is also related to *Bact. phaseoli*, but much less closely."

Rough colonies used to inoculate horse-radish leaves produced infections, but the pathogenic power of the organisms was apparently poor. Isolations from the lesions produced by rough colonies produced only smooth colonies.

In one set of plates, *Bacterium campestre*, isolated from spots produced by it on horse-radish leaves, produced only rough colonies, entirely similar in appearance to the rough colonies of the horse-radish bacteria. Some weeks later, in a second trial, isolation plates of *Bacterium campestre* from spots on horse-radish produced only smooth colonies and thus ruined the theory that an uncongenial host was responsible for the atypical colonies.

DATA ON THE HORSE-RADISH ORGANISM COMPARED WITH BACTERIUM CAMPESTRE AND BACT. PHASEOLI

Table 1 contains all the morphological, cultural, physiological, and serological data that the writer has been able to find in the publications of the various workers on *Bacterium campestre* and *Bact. phaseoli*. Every known available publication has been examined. Many of these, being mostly devoted to phases of the diseases other than the characters of the bacteria, have not been included in the bibliographical list. In this table all the characters of the horse-radish organism were determined by the writer. Some of the characters of *Bacterium campestre* and *Bact. phaseoli* were also determined by the writer in parallel tests with the horse-radish organism. In all cases the names or initials of the worker responsible for the determination of a character follow immediately after each statement.

TECHNICAL DESCRIPTION

Bacterium campestre armoraciae, n. var.

Short nonspore-forming rod; 0.7 to 2 by 0.3 to 0.5 μ, single or in pairs, on 48-hour-old beef-agar culture. Long chains form in beef broth plus 3 to 5 per cent NaCl. Motile by means of a single polar flagellum three to six times the length of the rod, stained from 48-hour-old beef-agar culture with Casares-Gil's stain; capsules; aerobic; Gram-negative; not acid-fast. Produces acid but no gas from dextrose, lactose, saccharose, glycerin, maltose, mannit, galactose, and levulose. Does not reduce nitrates. Liquefies gelatin and blood serum slowly. Milk is rapidly cleared without formation of curd. Abundant production of tyrosine crystals. Litmus in milk is slowly and irregularly reduced, not blued. Scanty growth in Uschinsky's solution, slightly better in Fermi's solution, and no growth in Cohn's solution. Beef-agar colonies are wax yellow, round, smooth, shining, translucent, flat, with entire margins; structure typically uniform but sometimes delicately striated or mottled. Beef broth moderately and evenly clouded, sometimes thin yellow rims and pellicles form. Ammonia, indol, and hydrogen sulphide are produced in small quantities. Strong diastatic action on starch. Optimum temperature, 28° C. to 30° C.; maximum, 36° C.; minimum, below 2° C.; thermal death point near 51° C. Pathogenic to horse-radish, causing numerous leaf spots.

SUMMARY

This paper describes a disease of horse-radish caused by *Bacterium campestre armoraciae*, n. var., not heretofore described. The disease is at present known to occur in Virginia, the District of Columbia, Connecticut, Missouri, and Iowa.

The causal organism has been isolated, and its pathogenicity has been proved by inoculation experiments. Infection is chiefly, probably always, through the stomata, producing definite lesions

in the parenchyma tissue. Numerous observations and isolation and inoculation experiments have failed to demonstrate any vascular infection.

In morphological and cultural characters the organism is very similar to *Bacterium campestre* and *Bact. phaseoli*, but it differs in its host relations and reactions.

Infections, in the form of leaf spots, due to the horse-radish bacteria can be forced on cabbage, cauliflower, and bean. The lesions remain small, the infection does not spread, and the character of the infection is unlike that caused by *Bacterium campestre* or *Bact. phaseoli*. Vascular infection did not occur on these plants from inoculation with the horse-radish bacteria.

Leaf-spot infections due to *Bacterium campestre* and to *Bact. phaseoli* can be forced on the horse-radish, but even under favorable conditions infections were seldom obtained. The leaf spots when produced are few in number but very similar in appearance to those produced by the horse-radish bacteria. No vascular infection occurred.

In general, the horse-radish bacteria grow more vigorously in most culture media than either *Bacterium campestre* or *Bact. phaseoli*, and the few cultural differences may possibly be explained by this fact.

The three organisms compared are not separable or are very slightly separable by morphological or cultural characters, as determined by present methods, but they do show specific host reactions.

Cultural characters and a technical description of the causal organism are given and also a table comparing the characters of the horse-radish organism (*Bacterium campestre* var. *armoraciae*) with those of *Bact. campestre* and *Bact. phaseoli*, as noted by the writer and other workers.

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THE USE OF ALINEMENT CHARTS IN CONSTRUCTING FOREST STAND TABLES [1]

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INTRODUCTION

Foresters have not ordinarily considered stand tables an essential part of a timber-yield table, yet such tables are necessary for the solution of certain management problems to which yield tables are ordinarily applied. It is commonly stated, for example, that one of the purposes of a yield table is to permit the determination of the best rotation. The technical rotation is defined as the minimum age at which material of a certain desired size can be produced. If a yield table of conventional form is consulted, information will be found therein which apparently permits the solution of this problem, namely, the average diameter and height attained at given ages, but on closer consideration it will be realized that there is danger of serious error in their use.

Suppose, for example, that the rotation is to be the shortest at which ties can be produced and that this product necessitates a minimum d. b. h.[2] of 12 inches (the height being unimportant). We may then determine from the yield table the age at which a 12-inch diameter is attained, but this is the age at which the average tree is just 12 inches. Since approximately 50 per cent of the trees in the stand are smaller than the average, these trees would not be merchantable according to the standards set. How much longer must we wait until all, or virtually all, of the trees are at least 12 inches in diameter? At that time will the larger trees have become too big for our specifications? If so, at what age will the maximum number of ties be produced? How much sooner could we have obtained, in thinnings, a few ties from the larger trees? All of these are questions of the highest practical importance which the conventional yield table can not answer. Obviously an adequate set of stand tables is needed to supplement the yield tables.

In this country, the first analytical attack on the problem of stand tables was made by Baker,[3] who suggested that the distribution of tree diameters in certain stands might follow the "law of normal frequency distribution" familiar to all students of statistical technic. He showed that for certain stands of western yellow pine (*Pinus ponderosa*) there was close agreement between the actual distributions and those called for by the normal Gaussian equation. This fact gives a ready means of determining the amount and character of the "dispersion" in the diameters of a stand, and hence suggests an answer to questions such as have been raised above.

It should not be assumed, however, that all stands conform to this normal law, and, as a matter of fact, further study has shown that several types of skewed frequency distributions are more common

[1] Received for publication Oct. 25, 1928; issued April, 1929.

[2] D. b. h.=diameter at breast height (4.5 feet above average ground level).

[3] BAKER, F. S. NOTES ON THE COMPOSITION OF EVEN-AGED STANDS. Jour. Forestry 21: 712-717, illus. 1923.

than the normal. There is need, therefore, for some simple method of testing conformity with the normal law, and for some way of handling the cases which do not conform. A technic which does both will be described in this paper, following a preliminary description of certain better-known methods, with a discussion of some of the difficulties encountered in their application.

THE USE OF PROBABILITY PAPER

A simple graphic method of testing conformity involves the use of what is known as probability paper, now commercially available. The rather peculiar system of graduations on this paper, and its use, can best be understood by referring first to Figure 1, A. This represents two normal frequency curves with their familiar symmetrical bell-like shapes. The ordinates may equally well be in absolute units (such as number of trees per acre per diameter class), or, as in the present illustration, in percentages of the total number of trees per acre. Figure 1, B represents the same information expressed in cumulative form. That is, each B curve shows the number of trees below given diameter limits. They may readily be obtained from A, by first reading the values for the diameter classes, and then adding them together progressively, starting with the smallest diameter class. Since each successive subtotal includes all trees below the upper limit of the highest diameter class involved, it should of course be plotted over this upper limit (2.5, 3.5, etc.), rather than over the central value (2.0, 3.0, etc.) as in A. These culmulative curves also may show either absolute numbers or percentages. When percentages are used the final value is of course universally 100 per cent. For present purposes the percentage form must be used.

These S-shaped cumulative frequency curves may now be anamorphosed[4] into straight lines by altering either the horizontal or the vertical scale. An altered horizontal scale would have no utility, for obviously that derived from curve PP would not apply to the curve QQ. If, however, either curve be anamorphosed vertically, the other will be found to become straight also. Thus may be obtained a form of chart applicable to all frequency distributions having the same maximum ordinate, a condition readily met by the use of percentages. Figure 1, C represents the anamorphosed curves. Probability paper in its commercial form is merely a printed grill work similar to that of C, but with much finer graduations.

To use this paper in testing the conformity of any stand to the "normal law" all that is necessary is to plot upon it the cumulative percentage frequency. If the distribution is normal, the resulting points will define a straight line. Unfortunately, however, failure to define a straight line may be an accident of sampling rather than a skewness in the distribution, particularly if the data at hand are few. In some instances the true explanation will be quite obvious, in others it will be dubious. Where a series of similar stand distributions are being examined simultaneously (as in a yield study), conformity may be determined more readily than in an isolated distribution. One distribution of such a series may suggest curvature in a given sense, but unless other distributions conform, this indication may well be disregarded.

[4] BRUCE, D. ANAMORPHOSIS AND ITS USE IN FOREST GRAPHICS. Jour. Forestry 21: 773-783, illus. 1923

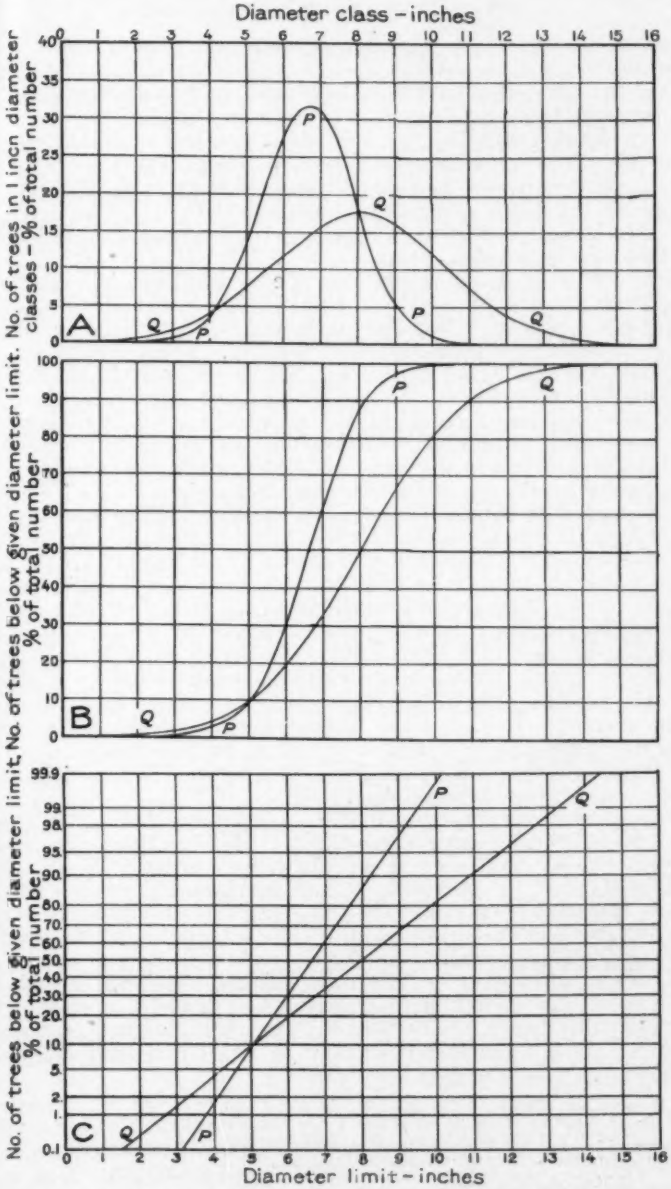
Diameter class - inches
No. of trees in 1 inch diameter classes - % of total number
A
P
Q
No. of trees below given diameter limit - % of total number
B
No. of trees below given diameter limit - % of total number
C
Diameter limit - inches

FIGURE 1.—Steps in the preparation of normal probability paper. The curves of A represent two stand tables conforming to the normal type of frequency distribution, the average diameter and standard deviations of Q exceeding those of P. In B the curves of A are given in cumulative form. In C the curves of B have been simultaneously anamorphosed into straight lines by modifying the vertical scale

PLOTTING FREQUENCY DISTRIBUTIONS

GROUPING BY SITE-AGE CLASSES

It is obvious that individual sample plots, such as are measured for the preparation of yield tables, will ordinarily contain too few trees to have regular stand distributions. It is therefore advisable to combine them into larger groups before plotting. The most obvious grouping is by site-age classes. So grouped the several plots can be combined by simple addition to form composite stand tables, one for each class, and these composites give a much improved definition of the frequency curves.

This system of grouping has been successfully used in connection with four species of southern pines.[5] The resulting cumulative frequency curves were found to conform to straight lines on probability paper in a fairly satisfactory manner. Many of the groups suggested curvature, but these indications were inconsistent and no systematic deviation from the normal form was apparent. Straight lines were therefore fitted to all the groups by eye. In fitting, the end points were given little consideration since the greatly expanded graduation intervals in the upper and lower portion of the grill tend to exaggerate relatively unimportant discrepancies.

It remained to harmonize the resulting straight lines representing the several site-age classes. This was found extremely easy because a close correlation was discovered between the average d. b. h. of the stand and both the position and tilt of the lines. Position is readily defined by the diameter corresponding to the 50 per cent frequency (the median) and tilt by the standard deviation which, being the difference between the diameter at 84 per cent and that at 50 per cent,[6] may readily be determined without computation by readings from the graphs. The d. b. h. at 50 per cent is of course equivalent to the average d. b. h., but this average has, essentially, been calculated by adding the diameters and dividing by the number of trees, and therefore differs somewhat from the average d. b. h. calculated from basal areas in the usual way.

When these two values were plotted over average d. b. h. (by basal area), well-defined curves resulted. By plotting these curves on frequency paper it is easy to calculate the frequency distribution appropriate to any given average d. b. h. and hence (since the average d. b. h. is given by the yield table) for any given age and site. With charts of this sort the questions raised at the beginning of this article may readily be answered.

A convenient method [7] of presenting this information is illustrated in Figure 2. Two horizontal auxiliary scales, A and B, are added to the probability paper, and by means of these the straight lines appropriate to given stand diameters may be located without reference to the curves just described.

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[5] BRUCE, D. A METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 32: 543–557, illus. 1926.

[6] In a normal frequency distribution the median and mean coincide, and 34 per cent of the data will lie between the mean and the mean plus the standard deviation.

[7] REINEKE, L. H. A MODIFICATION OF BRUCE'S METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 35: 843–856, illus. 1927.

GROUPING BY AVERAGE D. B. H.

An alternative method of grouping has been successfully used. Instead of combining all stands of a given site-age class, stands of a given average d. b. h. class may be thrown together. The result is a

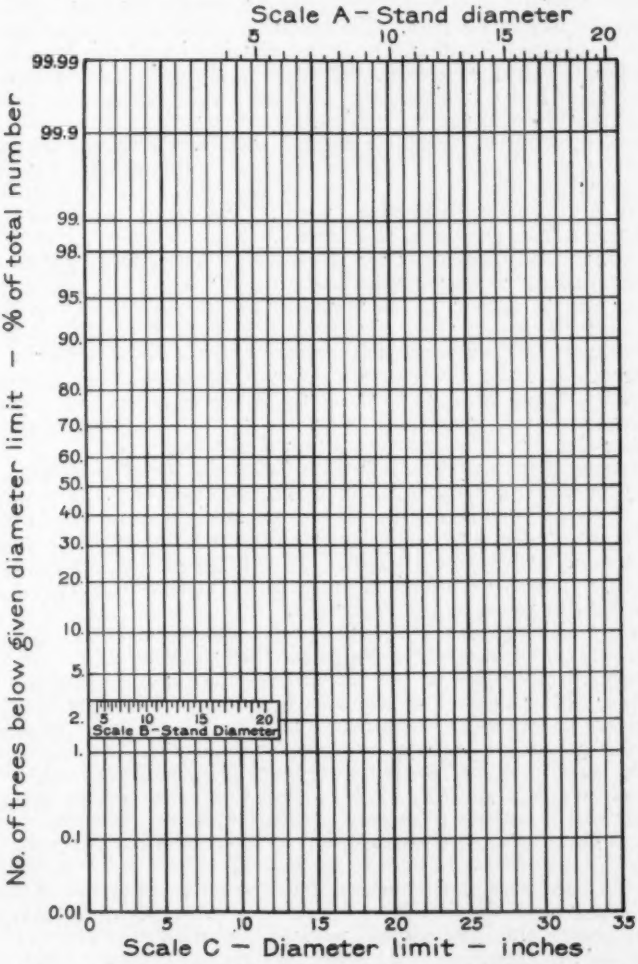

FIGURE 2.—Stand-table graph for loblolly pine on normal probability paper. For a stand of given average diameter draw a straight line passing through this value on both the A and B stand diameter scales. The intersection of this line with the vertical diameter lines of scale C will give the percentage of the total number of trees below that diameter in the average stand

smaller number of stronger curves. The only disadvantage is that it is no longer as easy to test the absence of any residual correlation with site and age as with the grouping originally mentioned.

DIFFICULTIES ENCOUNTERED IN PLOTTING SKEWED DISTRIBUTION AND VARIANT TYPES OF STAND

A certain type of skewed distribution may be easily handled by a slight modification of the foregoing method. This involves merely the substitution of a logarithmic diameter scale for that of uniform interval shown in Figure 1. The resulting curve then assumes a normal form.[8] Figure 3 illustrates a skewed distribution of this type both in simple and cumulative form and an anamorphosis of the cumulative distribution into a straight line. A species which apparently conforms closely to this logarithmic type is second-growth jack pine (*Pinus banksiana*), growing in dense, even-aged stands. With such a species virtually the same procedure as has just been outlined for normal distribution can be followed, changed only by the substitution of logarithmic probability paper for normal. The results may also be presented in a form analogous to Figure 2.

Unfortunately, many other species may have stand distributions which conform to neither the normal nor the logarithmic type. A rather simple variant is illustrated by red spruce (*Picea rubra*).[9] It has been found that these distributions become straight lines on logarithmic probability paper if 20 be added to the diameter limits, or in other words, if the diameter-limit scale of the logarithmic probability paper be shifted 20 units to the left. A correction of this sort must be determined by trial and error, but thereafter there need be no further difficulty nor departure from the method.

A more complex case is that of Douglas fir (*Pseudotsuga taxifolia*) for which a variable factor was found necessary. The cumulative distributions for this species become straight lines on logarithmic probability paper if to each diameter series a value equal to the average d. b. h. of the stand is added. It is still possible to use logarithmic frequency paper, but a form of presentation analogous to Figure 2 is a little difficult to use or to understand.

In appraising these methods that depend on normal and logarithmic frequency paper, it must be recognized that there are numerous disadvantages, which may be summarized as follows: A determination of whether either normal or logarithmic paper is adequate involves a considerable element of judgment and may in some cases be difficult. If neither appear adequate, a search for some correction system such as has been mentioned for red spruce and Douglas fir can only be conducted by trial and error. It is possible that other species or types of stands will be entirely refractory to this treatment. In complex cases, such as Douglas fir, the presentation of the results is awkward.

The fitting of straight lines to the individual data series is somewhat difficult because equal distances between points and the fitted line have unequal values on different portions of the graph. Even in more normal cases, the irregular grill work of the probability paper is somewhat hard to read.

The cumulative effect of these objections points to the need of some more adequate mechanism. Of course purely mathematical methods are available involving the calculation of coefficients of skewness and excess, but these are laborious and involve a certain

[8] This is anamorphosis in the broader meaning of the word, although the transformation is from one curve to another, instead of into a straight line.

[9] The data analyzed are those collected by W. H. Meyer in connection with the study of red spruce yields conducted by the Northeastern Forest Experiment Station.

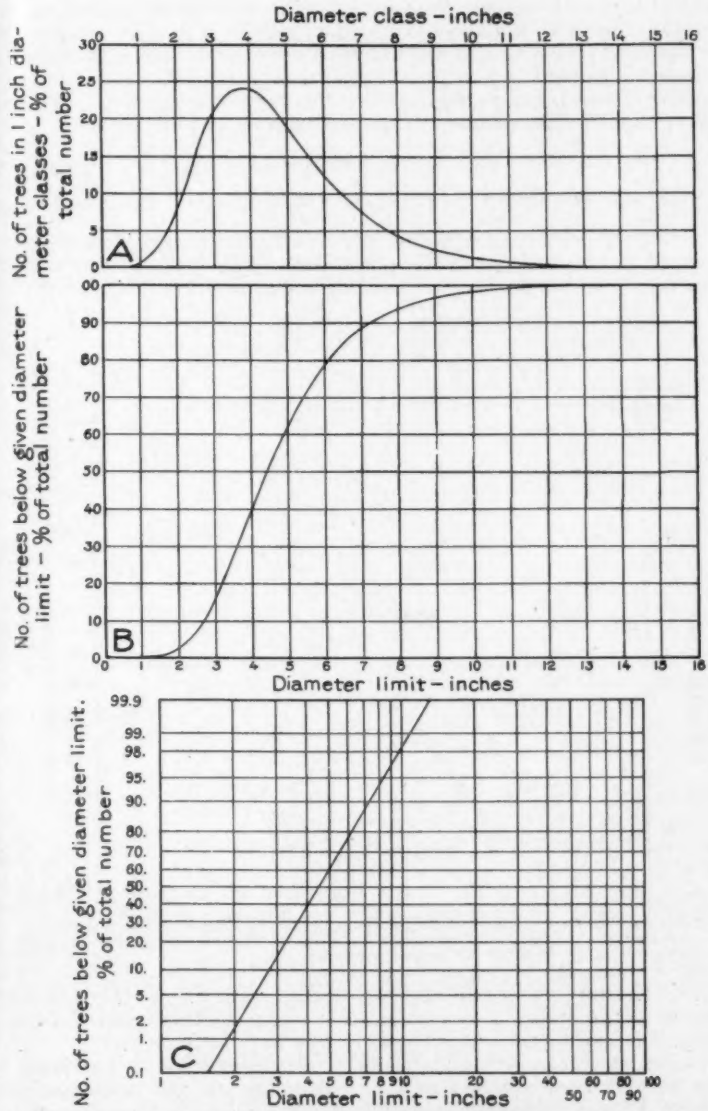
Diameter class – inches
No. of trees in 1 inch diameter classes – % of total number
A
No. of trees below given diameter limit – % of total number
B
Diameter limit – inches
No. of trees below given diameter limit. % of total number
C
Diameter limit – inches

FIGURE 3.—Steps in the preparation of probability paper for logarithmic frequency distributions. The curve of A represents a stand table conforming to the logarithmic type of frequency distribution. In B the curve of A is given in cumulative form, which unlike Figure 1, B, is not symmetrical about a horizontal line. In C this curve of B is anamorphosed into a straight line by using a horizontal logarithmic scale and a vertical scale modified as in Figure 1, C

rigidity of preliminary assumption. This is dangerous in the absence of either a more certain knowledge of the underlying laws or of any graphic check on the adequacy of the results. A graphic method has obvious advantages in flexibility and economy of time. It is such a mechanism based on alinement charts that this article aims to present. Before describing the application of this method directly to raw data, its relation to the probability paper method may be shown.

THE GRAPHIC METHOD BASED ON ALINEMENT CHARTS

RELATION BETWEEN THE GRAPHIC AND THE PROBABILITY PAPER METHODS

Although anamorphosis and alinement charts have both become quite common tools in forest mensuration, the relation between them has been little understood. As a matter of fact, the conditions that

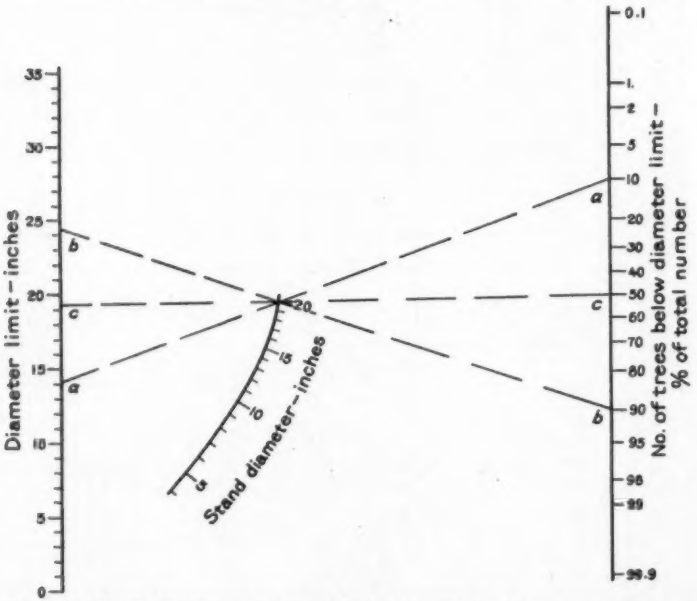

FIGURE 4.—Stand table alinement chart for loblolly pine. This chart is prepared from Figure 2 and gives identical readings. The construction lines *aa*, *bb*, and *cc* illustrate how the location of the curved axis at the 20-inch graduation is determined

permit the use of one are almost identical with those which permit the use of the other. Any system of straight lines produced by anamorphosis can be transformed easily into an alinement chart.[10] The transformation can be illustrated by converting Figure 2. In Figure 4 two parallel axes are laid out, corresponding to the perpendicular axes of Figure 2 (diameter limit and percentage) and graduated in the same manner. The scale unit of either may be increased or decreased at will but the proportionate distance between successive

[10] The converse is not equally true, as alinement charts with two or more curved axes are apparently not convertible into anamorphic form.

graduations must be retained. The readings of the frequency scale increase from top to bottom, while those of the diameter limit scale decrease.

The small horizontal scales (A and B) of Figure 2 defined, it will be remembered, the position of a series of straight lines each representing a frequency distribution corresponding to a given stand diameter. Each of the lines so defined will be represented on the alinement chart by a point. The positions of these points are determined as follows:

If the highest stand diameter for which information is available, 20 inches, be taken and a straight line be drawn across Figure 2 connecting graduation 20 on scales A and B, we may read from this line two pairs of values such as, for example, 10 per cent, 14.1 inches and 90 per cent, 24.4 inches. Straight lines (*aa*, *bb*) are drawn on Figure 4 connecting 10 per cent with 14.1 inches and 90 per cent with 24.4 inches. Their intersection is the required point corresponding to the 20-inch line of Figure 2. Its location, however, should be checked by drawing a third line. From Figure 2 we may also read on the 20-inch line 50 per cent, 19.3 inches, and the corresponding line (*cc*) on Figure 4 will be found to pass through the intersection of *aa* and *bb*. This shows that no errors have been made either in reading from Figure 2 or in drafting Figure 4. It will now be found that if a straightedge be laid across Figure 4 from any given diameter limit to this point, its intersection with the frequency axis will indicate a value which is identical with that obtainable from Figure 2 for the 20-inch stand diameter.

In a similar manner the position of points in Figure 4 corresponding to the other stand diameters of scales A and B, Figure 2, may be obtained. They will be found to lie along a perfectly defined curve which is therefore drawn in and appropriately graduated and labeled, as is shown in Figure 4. To avoid confusion, the construction lines similar to *aa*, *bb*, and *cc* for 20 inches are not shown for the other diameters. The final result is an alinement chart equivalent to Figure 2, but simpler in appearance and somewhat easier to read.

It is evident that a similar transformation is possible from logarithmic frequency paper. In such cases the frequency axes of the alinement chart would be laid out just as in Figure 4, but the diameter limit axis would be logarithmically graduated. For distributions like that of spruce, the adjustments of the alinement charts are entirely analogous to those of the frequency paper, and present no difficulties. The more complex distributions of the Douglas fir type are difficult to handle satisfactorily by either method.

There is, however, a second possible way of handling all the logarithmically skewed distributions. In Figure 3 the straight line results from a double anamorphosis, i. e., a frequency anamorphosis of the vertical scale superposed over a logarithmic anamorphosis of the horizontal. The anamorphosis transformation is virtually in two steps:

(1) The conversion of the skewed cumulative frequency curve (fig. 3, B) into a normal cumulative frequency curve (fig. 1, B) through the logarithmic graduation of the diameter axis, and (2) the conversion of the resulting normal curve into a straight line as in Figure 1, C.

Curves of the type of Figure 3, B may equally well be anamorphosed through a transformation of the vertical scale alone. The result is illustrated by Figure 5. It will be noted that while the horizontal scale is now uniform, the vertical is, in compensation, no longer symmetrical as in Figure 3, C, but is compressed in the lower portion and expanded in the upper.[11]

Obviously, an alinement chart for logarithmically skewed distributions may be prepared on this latter basis as well as on that already described. The deductions which may be drawn from this fact are most interesting, for it follows that in a frequency alinement chart such as Figure 4, logarithmic departures from the normal type of frequency can be cared for entirely by an alteration of the scale of the

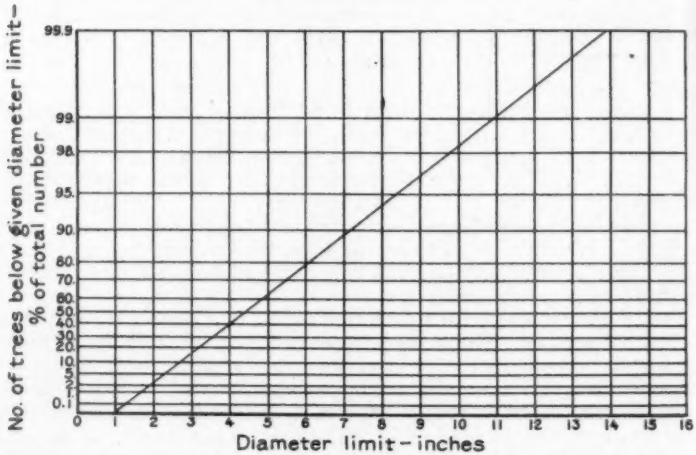

FIGURE 5.—The curve of Figure 3, B, anamorphosed into a straight line without the use of a logarithmic horizontal scale by modifying the vertical scale. Compare Figure 3, C

right-hand axis. The possibility at once suggests itself that ayn departures, whether logarithmic or not, might also be thus handled. If this proves to be the case, it should be possible to free ourselves from all preliminary assumptions as to the type of frequency distribution of the data under consideration, and graduate this right-hand axis empirically. It would then merely remain to determine, also empirically, the location of the central axis—the left-hand axis being assumed—and so build the chart directly from the basic data without the use of either type of probability paper.

DETERMINATION OF THE AVERAGE FREQUENCY CURVE

The first requisite is a method of determining the average frequency curve for all the data at hand. The natural form of summarizing, apparently dictated by the way in which the field data are collected is illustrated in Table 1.

[11] Logarithmic probability paper of this type is not, however, on the market.

TABLE 1.—*Natural form of summarizing field data on forest stands*

Average stand d. b. h.	Plots	D. b. h. class limits (upper), inches								
		1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
		Cumulative frequency percentages								
Inches	*Number*									
3.4	14	10.1	35.0	63.4	85.5	96.1	99.4	100.0	.....	.....
4.4	17	4.6	15.6	34.9	59.2	80.5	93.0	98.2	99.7	100.0

In this form no simple method of combining these figures into a series of average values is evident. If, however, a series of values be listed which states the average diameter limits at fixed frequency percentages instead of the average frequency at fixed diameter limits, weighted averages of the vertical columns will give the desired results. The required values may readily be obtained by graphic interpolation, i. e., by plotting each series in Table 1 and reading from the curves the values needed. In fitting these curves the points should be followed closely and no attempt should be made to harmonize them.

Probability paper is useful here (whether normal or logarithmic is immaterial), because the curves will be more nearly straight lines and hence easier to fit. The result will be shown in Table 2, taken from data for shortleaf pine (*Pinus echinata*). The final line, in which are entered averages (weighted by numbers of plots), is the required composite frequency distribution.

TABLE 2.—*Summary of data for shortleaf pine (Pinus echinata)*

Average stand d. b. h. (inches)	Basis, number of plots	Cumulative frequency, per cent										
		5	10	20	30	40	50	60	70	80	90	95
		Diameter limit (inches)										
3.4	14	1.2	1.5	1.9	2.3	2.7	3.0	3.4	3.7	4.2	4.8	5.3
4.4	17	1.6	2.1	2.8	3.3	3.7	4.1	4.5	5.0	5.5	6.2	6.7
5.4	19	2.0	2.6	3.5	4.1	4.5	5.0	5.5	6.0	6.6	7.4	8.1
6.4	29	1.8	3.0	4.2	4.9	5.5	6.0	6.6	7.2	7.8	8.8	9.6
7.4	20	1.7	2.8	4.9	5.8	6.4	7.0	7.6	8.2	9.0	10.1	11.5
8.3	22	1.9	3.2	5.1	6.3	7.2	7.9	8.7	9.5	10.2	11.5	12.7
9.5	21	3.2	5.3	6.7	7.6	8.3	9.1	9.8	10.5	11.4	12.7	13.7
10.4	15	5.0	6.4	7.7	8.6	9.4	10.0	10.8	11.6	12.5	13.5	14.4
11.4	13	4.9	6.4	8.2	9.5	10.2	11.3	12.0	12.8	13.5	14.7	15.8
12.3	8	5.0	6.7	8.7	10.0	11.2	12.1	13.0	14.0	14.9	16.1	17.1
13.4	6	7.8	9.1	10.6	11.9	12.7	13.2	13.9	14.5	15.1	16.5	17.5
14.0	2	7.0	9.3	11.0	12.1	13.0	13.9	14.6	15.5	16.5	17.9	19.0
15.5	1	10.0	11.3	12.7	13.6	14.5	15.2	16.0	16.8	17.7	19.0	20.0
Weighted totals	187	526.7	748.1	1,003.4	1,164.2	1,286.3	1,401.5	1,519.8	1,640.3	1,771.2	1,966.3	2,138.7
Weighted averages		2.8	4.0	5.4	6.2	6.9	7.5	8.1	8.8	9.5	10.5	11.4

CONSTRUCTION OF AN ALINEMENT CHART FROM THE COMPOSITE CURVE

It is interesting to plot this composite curve on normal frequency paper, since in the original investigation to which reference has already been made the normality of the individual curves was accepted. The plotted points defined with remarkable certainty a slightly curved

line on normal probability paper, thus showing that the assumption of normality was slightly in error. The departure is not pronounced and the error introduced by the assumption was evidently not serious, but the fact remains that we now have an improved form of frequency curve.

This curve may be used in constructing an alinement chart, which can conveniently be done on ordinary cross-section paper. Two parallel axes are drawn, as before, and on the right-hand axis a tempo-

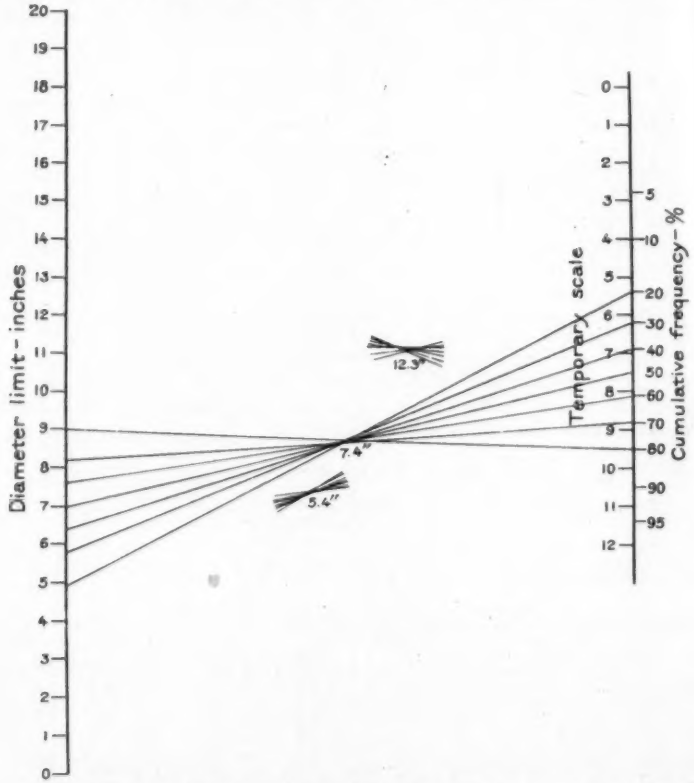

FIGURE 6.—The first steps in preparing an alinement chart stand table. The left-hand axis has been graduated with a uniform scale and the right in accordance with the composite frequency curve. Points on the central axis are being located by intersection

rary series of graduations having any convenient uniform scale which covers the range of the lowest line of Table 2 is entered. The frequency graduations are then entered directly by means of this series. The 5 per cent graduation, for example, is placed opposite 2.8 on the temporary scale, 10 per cent opposite 4.0, etc. The results are shown in Figure 6.

The left-hand axis is graduated uniformly, using any convenient unit which permits an adequate range of values. Points on the central

axis are then located by intersections in a way quite similar to that already described. In the present instance, however, since we are now working with raw data, the various lines associated with each stand diameter class will no longer intersect at exactly the same point. It is well to omit altogether the weaker end-values below 20 per cent and above 80 per cent. The intersections of the others will be somewhat as is illustrated in Figure 6 where three fairly typical series are

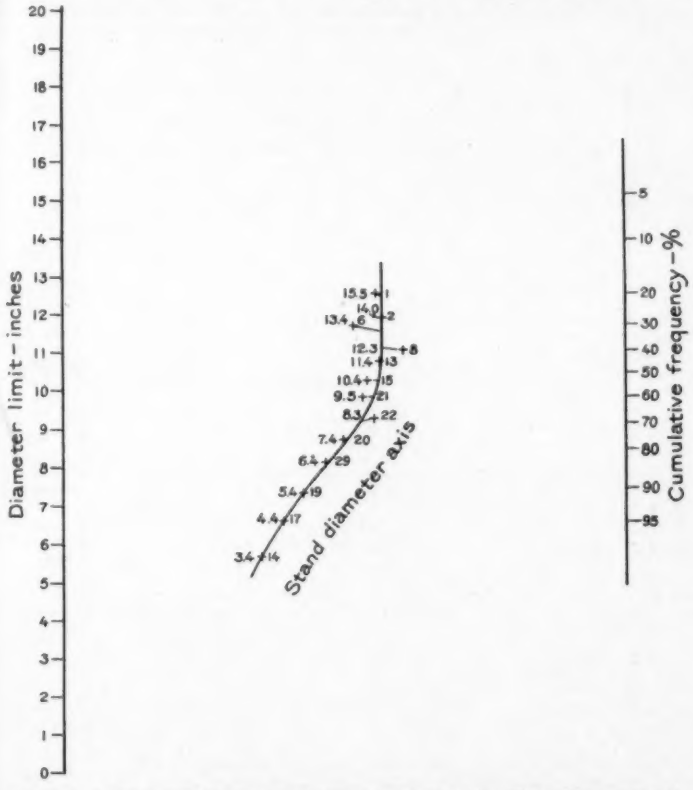

FIGURE 7.—Further steps in preparing an alinement chart stand table. The small crosses indicate the positions of the points located by intersections as illustrated by Figure 6. The adjacent numbers are the corresponding stand diameters and weights (number of plots). The curve fitted to these points is the central axis on which the scale of stand diameters will be entered. The light lines connecting crosses to the axis indicate the position on the axis corresponding to each point

shown. The point 5.4 is quite definitely fixed while the point 12.3 is less so. Our task is to select a point in each network of intersections which is the best compromise among the conflicting indications. The selection of this point is analogous to and replaces the fitting of a curve on probability paper in the method first described.

When these points have all been selected the intersecting lines may be erased and the series of the points will appear as in Figure 7, the two numbers entered beside each point being the average stand

diameter which it represents and the number of plots used for determining the point. With the paper turned on its side, a curve is next fitted to these points. This will serve as the axis for the stand diameter.

It remains to graduate this axis. Each point used to locate the axis may also be used to locate its graduations by constructing a

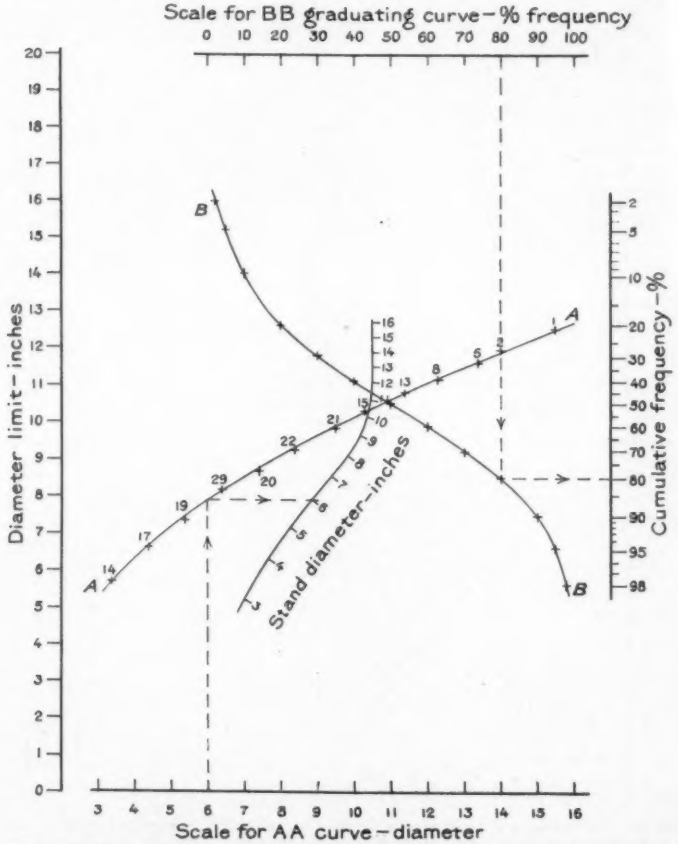
Scale for BB graduating curve—% frequency
0 10 20 30 40 50 60 70 80 90 100
Diameter limit—inches
Cumulative frequency—%
Stand diameter—inches
Scale for AA curve—diameter
3 4 5 6 7 8 9 10 11 12 13 14 15 16
A
B

FIGURE 8.—The completion of the alinement chart stand table. AA is the graduating curve for the central axis and is fitted to points derived from those on the axis in Figure 7. The final graduating of the central axis is done by means of this curve. BB the graduating curve for the frequency axis, is used to adjust the spacing of the frequency graduations, and to enter intermediate values. AA and BB are omitted from the final chart

graduating curve such as is shown in Figure 8, AA. Each point which lies on the curve in Figure 7 here appears as the point of corresponding weight with ordinate equal to its vertical position and abscissa equal to its nominal value. For example, the lowest point in Figure 7 represents 3.4 inches and is situated 5.7 units above the base line of the graph. (For convenience the units used are those of the left-

hand axis.) On Figure 8 this point appears with the 5.7 plotted over the 3.4, etc. Points which in the earlier graph did not lie exactly on the curve must be shifted over to it before transference to the graduating curve. These shifts, indicated by fine lines in Figure 7 connecting points to the axis, are not horizontal but along a line passing through the 50 per cent graduation of the frequency scale. The points transferred to Figure 8 will be seen to define a smooth curve, which is drawn in. The graduations on the central axis can now be entered by reference to this curve, the vertical position of each graduation being equal to the ordinate of the curve at 4, 5, 6, etc., inches.

It is well to prepare a similar graduating curve, BB, for the frequency axis. Minor irregularities in the graduation intervals may be adjusted by means of this curve and as many intermediate graduations as are necessary may be inserted.

In actual practice Figures 6, 7, and 8 may be drawn on a single sheet, much of the work being done in pencil and later erased. If a permanent record of the intermediate steps is desired, inks of different colors may be used and the final chart may be a tracing of the three main axes alone.

If no difficulties have been encountered, this completes the work, which results, with relatively little labor, in a chart which is simple in appearance, easy to use, and fitted to the data more accurately than would be possible in most cases had probability paper been used. The procedure, moreover, is identical whether the distributions are normal, logarithmic, or of the type described for red spruce.

CONSTRUCTION OF AN ALINEMENT CHART FOR THE COMPLEX DOUGLAS FIR DISTRIBUTION

If a more complex form, like the Douglas fir distribution, is encountered, its complexity may be detected when attempting to locate the central axis by intersections. The definition of the several points of common intersection will of course be largely governed by the size of the sample and must be judged only when this is taken into consideration, but any systematic tendency toward multiple intersections, however slight, suggests a complex frequency form. For example, in working with the Douglas fir data it was found that while the lines associated with the lower frequencies and lower diameters intersected quite sharply, those for higher values of either were erratic. The method by which such an abnormality as this may be provided for will next be described. The data available for Douglas fir are so many that complete presentation here is impracticable, but illustrative tables and graphs will permit the reader to follow the successive steps.

The basic data were from 235 plots.[12] These data, treated as has already been described, are summarized in Table 3.

[12] These were measured by R. E. McArdle for the study of Douglas fir yields conducted by the Pacific Northwest Forest Experiment Station.

TABLE 3.—*Summary of stand table data for Douglas fir*

Average stand d. b. h. (inches)	Basis, number of plots	Cumulative frequency (per cent)												
		2	5	10	20	30	40	50	60	70	80	90	95	98
		Diameter limit (inches)												
3.8	1	1.4	1.6	1.9	2.2	2.6	2.9	3.2	3.6	4.0	4.6	5.4	6.2	7.3
4.5	3	1.5	1.8	2.2	2.6	3.0	3.4	3.8	4.3	4.8	5.5	6.6	7.6	8.8
5.4	4	1.6	2.0	2.4	2.8	3.4	3.9	4.5	5.2	5.9	6.7	8.0	9.2	10.4
6.5	8	1.8	2.3	2.8	3.6	4.2	4.9	5.6	6.2	7.2	8.0	9.4	10.7	12.2
7.7	5	2.7	3.2	3.8	4.5	5.2	5.9	6.7	7.4	8.3	9.5	11.0	12.4	14.0
8.4	13	3.4	4.1	4.7	5.5	6.3	6.9	7.5	8.3	9.2	10.3	11.6	12.9	14.4
9.5	12	3.7	4.5	5.2	6.1	6.9	7.7	8.4	9.4	10.3	11.7	13.2	14.5	16.4
10.4	15	4.4	5.1	5.8	6.8	7.7	8.5	9.4	10.4	11.4	12.6	14.4	15.8	17.6
11.5	9	4.4	5.4	6.2	7.4	8.4	9.4	10.4	11.5	12.5	14.0	16.2	17.8	19.6
12.5	14	5.0	6.0	6.9	8.2	9.2	10.3	11.5	12.6	13.8	15.2	17.3	19.1	21.0
13.4	19	5.7	6.8	7.8	9.0	10.1	11.2	12.2	13.7	14.8	16.3	18.3	20.0	22.0
14.4	27	5.5	6.9	8.0	9.6	10.8	12.1	13.3	14.7	16.0	17.7	19.8	21.3	23.2
15.5	17	5.6	7.2	8.7	10.4	11.8	13.1	14.5	15.9	17.4	19.0	21.4	23.2	25.3
16.4	18	7.0	8.1	9.4	11.2	12.8	14.1	15.4	16.9	18.3	20.1	22.2	24.2	26.4
17.5	16	7.5	8.8	10.0	11.8	13.4	14.8	16.3	17.9	19.3	21.2	23.7	25.9	28.3
18.4	11	8.7	9.9	11.2	13.2	14.7	16.0	17.4	19.0	20.5	21.9	24.3	26.1	28.2
19.5	9	8.3	10.4	11.7	13.7	15.4	17.2	18.5	20.1	21.8	23.4	25.8	27.8	29.9
20.5	8	9.5	10.9	12.4	14.5	16.3	17.7	19.5	21.0	22.5	24.5	27.3	28.1	31.8
21.6	7	10.2	11.5	12.6	14.9	16.8	18.5	20.3	22.0	23.9	26.0	28.6	31.0	33.2
22.2	4	9.8	11.4	12.7	15.2	17.0	19.0	20.9	22.9	24.7	26.8	29.9	32.6	34.8
23.3	1	10.5	12.6	14.3	16.8	18.8	20.7	22.1	23.9	25.7	27.5	30.5	33.5	35.2
24.3	1	10.3	11.8	13.5	16.3	18.8	21.1	23.5	24.1	27.1	29.0	32.0	35.0	39.1
25.3	2	11.5	12.9	14.8	17.4	19.7	22.0	24.0	26.0	28.0	30.0	33.5	36.0	40.0
26.5	2	11.9	13.9	15.6	18.5	20.8	23.3	25.7	27.8	30.0	32.0	35.0	36.8	40.1
27.6	5	12.2	14.2	16.0	19.2	21.8	24.5	27.0	28.9	31.5	34.0	36.0	39.0	41.8
28.4	3	12.4	14.1	15.8	19.0	22.4	25.1	27.7	30.0	32.2	34.5	38.0	40.6	44.0
32.4	1	18.0	19.5	21.8	25.8	28.0	30.1	31.9	33.5	35.2	37.3	40.7	43.5	45.9
Weighted total	235	1,443.2	1,716.9	1,968.2	2,331.3	2,637.4	2,926.8	3,214.8	3,525.7	3,834.1	4,201.4	4,697.4	5,103.1	5,590.5
Weighted average		6.1	7.3	8.4	9.9	11.2	12.5	13.7	15.0	16.3	17.9	20.0	21.7	23.8

The procedure at first is identical with that already outlined. An alinement chart is blocked out with the left-hand axis graduated at arbitrary uniform intervals for diameter limit, and the right-hand axis (scale A) graduated to agree with the final line of Table 3. (To avoid confusion, the temporary scale is not shown.) In locating the central axis by intersections, however, points are chosen on the basis of those lines which do meet approximately in a common point (30 to 70 per cent), entirely disregarding all others. The axis curve is fitted to these points and graduated as before, and the result (fig. 9) is considered as a first approximation chart.

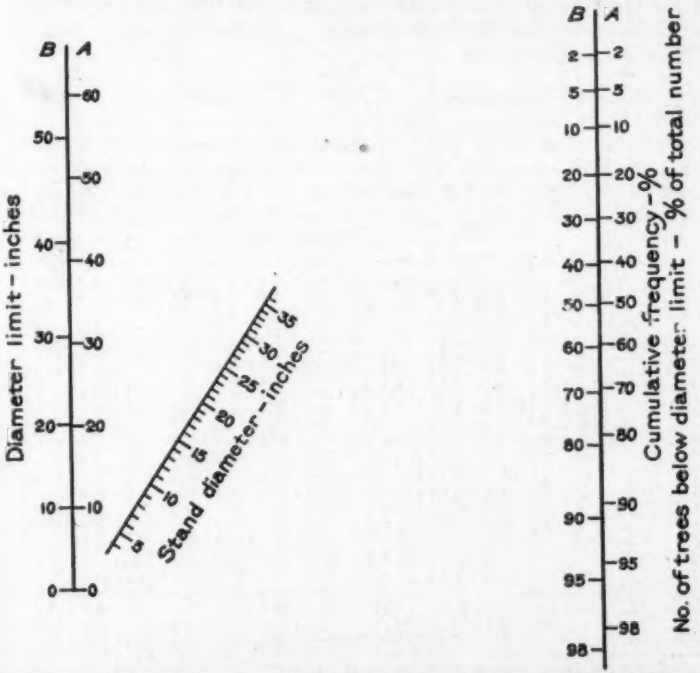

FIGURE 9.—An alinement chart stand table for Douglas fir. Frequency scale A is derived from the bottom line of Table 3. Diameter limit scale is assumed. The intermediate axis is located and graduated by the use of only those construction lines which have satisfactory mutual intersections (30 to 70 per cent). The result is a first approximation chart. Subsequent corrections first alter the diameter-limit scale, and later the frequency scale. The B scales constitute the final chart

It is obvious that both the central and right-hand axes can not be materially improved at this point, so attention must next be turned to the possibility of securing better results by shifting the graduations on the left-hand axis which in the previous case remained uniformly graduated. This possibility can be tested by reading the chart backward and determining for given stand diameters and given frequency percentages a series of "estimated" diameter limits. If this is done for values which correspond to the upper row and left-hand column of Table 3, a series of values similar in form to this table may be derived. Such a series is shown in Table 4. Were

the chart perfectly fitted to the data, Tables 3 and 4 would, in fact, be identical. Any differences between the estimated and measured diameter limits are to be taken as indications that a change in the position of one of the graduations of the left-hand axis may be made. It can profitably be made, however, only if the various indications are in harmony. Whether they are may be determined by plotting the values from Table 3 over the corresponding values from Table 4, assigning as weights the number of plots. The number of points thus obtained would be large, and it is preferable first to group them by "estimated" diameter classes (2-inch classes were used here because of the large range of diameters) and then plot the resulting weighted averages (measured over estimated). The resulting points and curve are shown in Figure 10.

TABLE 4.—*First estimates from Figure 9 to be compared with Table 2*

Average stand d. b. h (inches)	Basis, number of plots	Cumulative frequency (per cent)											
		2	5	10	20	30	40	50	60	70	80	90	95	98
		Diameter limit (inches)												
3.8	1	0.7	1.0	1.4	1.9	2.3	2.8	3.2	3.5	4.0	4.5	5.2	5.7	6.3
4.5	3	1.0	1.5	1.9	2.4	2.9	3.4	3.9	4.3	4.8	5.3	6.0	6.7	7.4
5.4	4	1.5	1.9	2.4	3.0	3.5	4.1	4.7	5.2	5.7	6.3	7.2	7.9	8.8
6.5	8	1.9	2.5	3.0	3.7	4.4	5.0	5.6	6.2	6.8	7.5	8.5	9.4	10.3
7.7	5	2.6	3.2	3.9	4.7	5.5	6.2	6.9	7.6	8.4	9.2	10.3	11.3	12.4
8.4	13	2.9	3.6	4.3	5.1	6.0	6.8	7.5	8.3	9.1	9.9	11.1	12.2	13.4
9.5	12	3.5	4.2	5.0	6.0	6.8	7.8	8.6	9.4	10.3	11.2	12.6	13.8	15.2
10.4	15	3.8	4.7	5.5	6.5	7.5	8.5	9.4	10.2	11.2	12.3	13.8	15.0	16.5
11.5	9	4.4	5.3	6.2	7.4	8.5	9.5	10.5	11.5	12.5	13.7	15.3	16.7	18.3
12.5	14	5.0	6.0	7.0	8.2	9.4	10.5	11.5	12.6	13.8	15.0	16.8	18.3	20.0
13.4	19	5.4	6.5	7.6	8.9	10.1	11.3	12.5	13.6	14.8	16.1	18.0	19.7	21.5
14.4	27	5.9	7.0	8.1	9.6	10.8	12.2	13.4	14.6	15.9	17.3	19.3	21.1	23.0
15.5	17	6.5	7.8	8.9	10.4	11.8	13.2	14.5	15.8	17.2	18.7	20.9	22.8	24.9
16.4	18	6.9	8.2	9.5	11.0	12.5	14.0	15.4	16.7	18.2	19.8	22.1	24.0	26.2
17.5	16	7.5	8.8	10.1	11.8	13.3	14.9	16.3	17.8	19.4	21.0	23.4	25.4	27.8
18.4	11	8.0	9.4	10.8	12.5	14.2	15.8	17.4	18.9	20.6	22.3	24.9	27.0	29.5
19.5	9	8.5	10.0	11.5	13.4	15.1	16.8	18.5	20.1	21.9	23.7	26.3	28.6	31.1
20.5	8	9.0	10.6	12.1	14.1	15.8	17.7	19.4	21.1	22.9	24.8	27.6	30.0	32.8
21.6	7	9.5	11.1	12.8	14.9	16.7	18.6	20.5	22.2	24.1	26.1	29.1	31.6	34.5
22.2	4	9.8	11.4	13.1	15.2	17.2	19.1	20.9	22.8	24.7	26.7	29.7	32.3	35.2
23.3	1	10.4	12.2	13.9	16.0	18.1	20.2	22.1	24.0	26.0	28.2	31.3	34.0	37.2
24.3	1	10.9	12.8	14.6	16.9	19.1	21.2	23.2	25.2	27.4	29.6	33.0	35.7	39.0
25.3	2	11.4	13.5	15.3	17.7	20.0	22.2	24.3	26.3	28.6	30.9	34.4	37.4	40.7
26.5	2	12.1	14.1	16.0	18.6	21.0	23.2	25.4	27.5	29.9	32.3	35.9	39.1	42.5
27.6	5	12.6	14.7	16.7	19.4	21.8	24.2	26.5	28.7	31.2	33.7	37.5	40.7	44.4
28.4	3	13.1	15.4	17.5	20.3	22.8	25.3	27.6	29.9	32.5	35.2	39.0	42.4	46.1
32.4	1	15.4	18.0	20.4	23.5	26.4	29.2	32.0	34.6	37.6	40.7	45.1	49.0	53.3

The curve is exceedingly well defined. Up to 20 inches it is a 45° straight line, and the measured values are almost exactly the same as the estimated values, but above that point the estimated diameters are increasingly greater than the measured diameters. This means that the differences between Tables 3 and 4 for small diameters are erratic rather than systematic and so can not be remedied by any change in the diameter limit axis. Above 20 inches, however, corrections can properly be made. Since, for example, the curve shows that an actual value of 40 corresponds to a first-estimate value of 42.3, the required correction is to shift the 40 graduation to the position of the 42.3 graduation, etc. A graduating curve (fig. 8) may be useful in making these shifts.

When the diameter limit axis has thus been regraduated the resulting chart may be considered a second approximation chart, more

accurate than the first but still, perhaps, susceptible of improvement. The changes made in the diameter limit graduations may be considered equivalent to a partial anamorphosis of the diameter scale. This may have made it desirable to revise the anamorphosed frequency axis. This possibility is tested by computing a table, similar to Table 4, of what may be called "second estimates" based on the revised chart. The averages (weighted) of the vertical columns of the table of second estimates (not shown) are now to be compared. The results are found to be in Table 5.

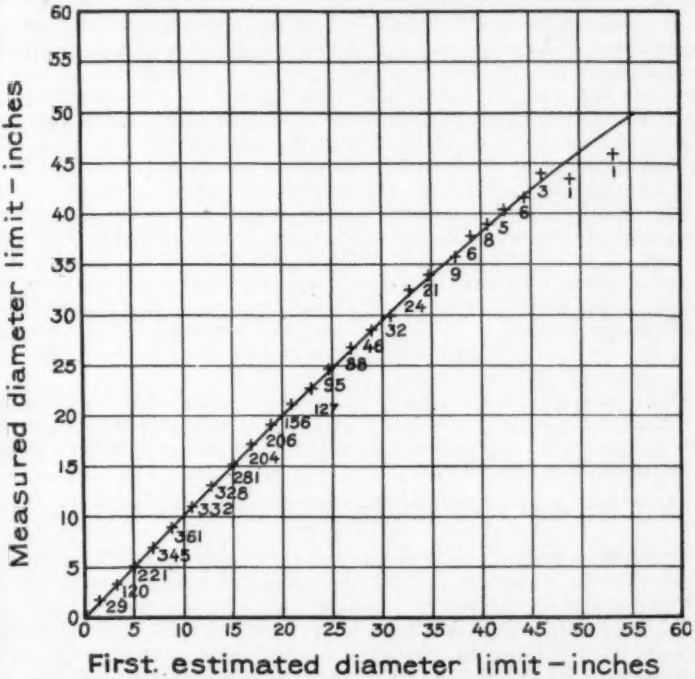

FIGURE 10.—The curve of measured over estimated diameter limits obtained by plotting values from Table 3 over corresponding values from Table 4. This curve is used to regraduate the diameter limit axis of Figure 9. This step is necessary only with complex frequency distributions. With simple distributions this curve will be a 45° straight line through the origin, indicating that no corrections need be made

TABLE 5.—*Second estimate table computed from Table 3*

Frequency percentages	Average measured diameter limit	Average second estimated diameter limit	Difference from second estimate	Difference curved	Frequency percentages	Average measured diameter limit	Average second estimated diameter limit	Difference from second estimate	Difference curved
	Inches	*Inches*				*Inches*	*Inches*		
2	6.1	6.1	0.0	+0.05	60	15.0	14.9	+0.1	+0.10
5	7.3	7.2	+.1	+.05	70	16.3	16.2	+.1	+.15
10	8.4	8.4	.0	+.05	80	17.9	17.5	+.4	+.30
20	9.9	9.8	+.1	+.05	90	20.0	19.5	+.5	+.45
30	11.2	11.1	+.1	+.05	95	21.7	21.2	+.5	+.55
40	12.5	12.5	.0	+.05	98	23.8	23.1	+.7	+.70
50	13.7	13.7	.0	+.05					

An inspection of this series of values shows that the indicated corrections for all but the highest percentages are small and possibly due to chance. This was to have been expected, for no changes had been made in the portions of the chart which apply to these lower frequency percentages. The computation of these lower values might well then have been omitted, although useful as a check on the graphic work of preparing the chart. At the upper end of the frequency scale, where the differences are larger and suggest a definite trend, the frequency graduations (from 80 per cent up) should be shifted. The differences are therefore curved as shown above.

The shift is readily accomplished by reference to the "temporary scale" (fig. 6) by means of which the frequency axis was originally graduated. The 98 per cent graduation, for example, is shifted upwards (on account of the plus sign) by 0.7 of a temporary scale unit; the 95 per cent graduation by 0.55 of a unit; the 90 per cent graduation by 0.45, etc. If these shifts are transferred to the frequency graduating curve and the latter curve readjusted to conform, any desired intermediate graduations may readily be inserted.

It would be possible to carry on this progressive series of improvements by a further revision of the graduations of the diameter axis, or perhaps even by relocating and regraduating the central axis, but there is every evidence that for Douglas fir further improvements would be too slight to warrant the labor involved. If a final table of third estimates similar to Tables 3 and 4 is prepared, it will be found that the differences between its values and those of Table 3 are small and apparently entirely erratic.

The final chart for Douglas fir is illustrated by the B scales in Figure 9. Except on close inspection it is no more complex than Figure 4 which represented a frequency distribution of the normal type and it is no more difficult to use.

UTILITY AND LIMITATIONS OF THE ALINEMENT CHART METHOD

It would be premature to claim that every type of frequency curve which may be encountered in all the many species and varied stands can be handled by this technic, but the method so far has not yet failed and is so flexible that this hope is perhaps justified. Its flexibility extends its usefulness to frequency distributions of other data, such as basal area or volume in cubic feet. It is obvious that if the frequency distribution of numbers of trees is normal, that for basal area or volume must be skewed and the latter (due to the influence of height and perhaps of form factor) in a complex way. Experience has shown, however, that such problems can be solved by the alinement chart method as easily as those which have been here illustrated.

The frequency distribution of volumes in board feet is more abnormal and apparently can not thus be analyzed. The difficulty is caused by the rigid lower limit of merchantability which distorts the distribution of the stands of smaller average d. b. h. without affecting those which are larger. If the alinement chart method is applicable at all, the form of the chart must be so radically altered as to vitiate its usefulness.[13] With this one exception, however, all the frequency distributions yet analyzed by this method have been easily handled.

[13] Board foot distributions can be presented graphically, however, by a series of harmonized frequency curves, preferably on probability paper.

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